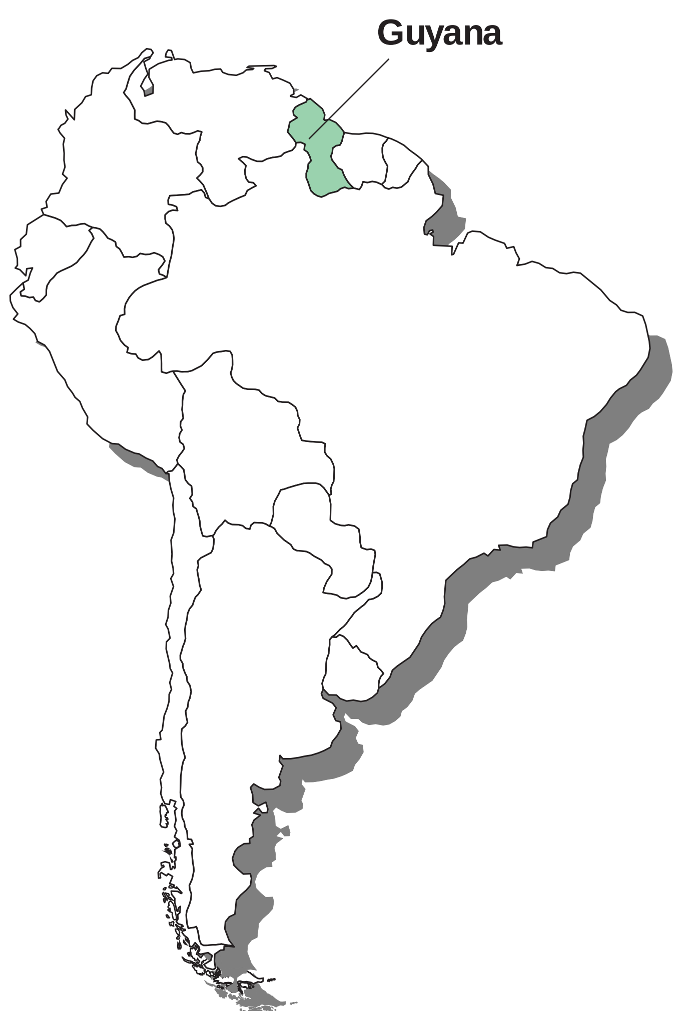
WATER RESOURCES ASSESSMENT OF GUYANA



US Army Corps of Engineers
Mobile District &
Topographic Engineering Center

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Executive Summary

Guyana, meaning “land of many waters,” is rich in hydrologic resources. Most of the population and economic base of the country is concentrated in the low-lying coastal plains, much of which is below sea level. This area is subject to inundation, and is protected by a series of sea walls, which compose a coastal sea defense system. Repairs and maintenance of the sea defenses are very expensive, thus the system is in a state of disrepair, and the coastal areas are sometimes “flooded” by the sea.

Throughout the populated coastal plain and part of the interior highlands, there is a system of drainage and irrigation canals that feed shallow reservoirs, known as “conservancies,” that are designed to provide primarily irrigation water and secondarily other water needs. These drainage and irrigation systems have deteriorated because of lack of maintenance and can no longer sufficiently provide irrigation, much less other water needs. The lack of storage capacity has hindered agricultural production, which is one of the most important sectors of the economy. As a result of surface water supply shortages, ground water is being used to supplement the domestic water requirements. Ground water from the coastal aquifer system, which consists of three distinct aquifers, provides about 90 percent of the domestic water for the country. Presently, these aquifers, particularly the “A Sand” aquifer, provide ample water for the country’s coastal population. However, from approximately 1913 to 1993, dewatering of the “A Sand” aquifer caused the head to fall almost 20 meters. Long-term studies on this aquifer system are needed to determine its capability to sustain increased withdrawals, as ground water will be more heavily relied upon to provide more of the water supply.

Hydrologic data are lacking throughout the country, particularly since the late 1960’s when data collection decreased dramatically. Although no hydropower power exists, the water resources of the country offer significant potential, but development is prohibited by difficult access due to lack of roads. Wastewater treatment is minimal nationwide. As a result, surface water is laden with sewage, particularly in the heavily populated coastal areas.

Preface

In 1995 the U.S. Southern Command Engineer's Office commissioned the U.S. Army Corps of Engineers District in Mobile, Alabama, and the U.S. Army Corps of Engineers Topographic Engineering Center in Alexandria, Virginia, to conduct a water resources assessment of Guyana. This assessment has two objectives: (1) to provide U.S. military planners with accurate information for planning various joint military training exercises and humanitarian civic assistance engineer exercises; and (2) to provide an analysis of the existing water resources of Guyana and identify some opportunities available to the Government of Guyana to maximize the use of these resources.

Special thanks go to Mr. Thomas Whitney, U.S. Agency for International Development, for his exceptional cooperation and support. Without Mr. Whitney's assistance, our tasks could not have been accomplished.

A team consisting of the undersigned water resources specialists from the U.S. Army Corps of Engineers Mobile District and the U.S. Army Topographic Engineering Center conducted the water resources investigations during January 1997 and subsequently prepared the report.

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List of Acronyms and Abbreviations

Acronyms

CARE	Cooperative for American Relief to Everywhere
GSWC	Georgetown Sewerage and Water Commission
GUYWA	Guyana Water Authority
HCA	humanitarian civic assistance
USACE	U.S. Army Corps of Engineers (referred to in text as Corps)
USAID	U.S. Agency for International Development
USSOUTHCOM	U.S. Southern Command

Abbreviations

Ca	calcium
$CaCO_3$	calcium carbonate
Cl	chloride
cfs	cubic feet per second
CN	carbon-nitrogen
Fe	iron
gal/d	gallons per day
gal/h	gallons per hour
gal/min	gallons per minute
H_2S	hydrogen sulfide
km^2	square kilometers
L/min	liters per minute
m^3/s	cubic meters per second
Mg	magnesium
mg/L	milligrams per liter
mi^2	square miles
mm	millimeters
Mm^3	million cubic meters
MW	megawatts
NaCl	nitrogen-chloride
NO_2	nitrogen-oxygen
NO_3	nitrate
pH	potential of hydrogen
ROWPU	reverse osmosis water purification unit
TDS	total dissolved solids (the sum of all dissolved solids in water or waste water)

List of Place Names

Place Name	Geographic Coordinates
Barama River	0740N05915W
Barima River	0835N06025W
Berbice	0527N05757W
Berbice River	0617N05732W
Canje River	0616N05732W
Courantyne River	0557N05706W
Cuyuni River	0623N05841W
Demerara River	0648N05810W
Enterprise	0732N05840W
Essequibo River	0659N05823W
Georgetown	0648N05810W
Guyana	0500N05900W
Guyana Shield (highlands)	0430N05937W
Kanuku Mountains	0312N05935W
Kauramembu Mountains	0712N05935W
Linden	0600N05818W
Mazaruni River	0625N05838W
Merume Mountains	0548N06006W
New River	0323N05736W
Omai River	0526N05845W
Pakaraima Mountains	0442N05913W
Pomeroon River	0737N05845W
Potaro River	0522N05854W
Rupununi Savannahs	0300N05930W
Rupununi River	0403N05834W
Takutu River	0431N05813W
Waini River	0824N05951W

Note:
Geographic coordinates for place names and primary features are in degrees and minutes of latitude and longitude. Latitude extends from 0 degrees at the Equator to 90 degrees north or south at the poles. Longitude extends from 0 degrees at the meridian established at Greenwich, England, to 180 degrees east or west established in the Pacific Ocean near the International Date Line. Geographic coordinates list latitude first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or Western (W) Hemisphere. For example:

Atlantic Ocean 0700N05800W

Geographic coordinates for the Atlantic Ocean that are given as 0700N05800W equal 07°00'N, 58°00'W and can be written as a latitude of 7 degrees and 0 minutes north and a longitude of 58 degrees and 0 minutes west. Coordinates are approximate. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Geographic coordinates for rivers are generally at the river mouth.

Figure 1. Country Map

I. Introduction

The gift of water nourishes and sustains all living things. At least 400 million people in the world live in regions with severe water shortages. By the year 2050, it is expected to be four billion people. The projected short supply of usable potable water could result in the most devastating natural disaster since history has been accurately recorded, unless something is done to stop it. Twenty-two countries are dependent on the flow of water from other nations for much of their supply, a dependency which can lead to friction, escalating tensions or worse. More than a dozen nations obtain most of their water from rivers that cross the borders of neighboring countries, which can be viewed as hostile. Even when nations are on the best of terms, there are serious disagreements over water-sharing issues.

The purpose of this assessment is to document the general overall water resources situation in Guyana. This work involves describing the existing major water resources in the country, identifying special water resources needs and opportunities, documenting ongoing and planned water resources development activities, and suggesting practicable approaches to short- and long-term water resources development. This assessment is the product of an in-country information-gathering trip, plus information obtained in the United States on the part of four water resources professionals. The scope was confined to a “professional opinion” given the size of the country and the host of technical reports available on the various aspects of Guyana’s water resources.

This information can be used to support current and potential future investments in managing the country’s water resources, and to assist military planners during troop engineering exercise and theater engagement planning. The color surface water and ground water graphics, complemented by the tables in Appendix C, should be useful to water planners as overviews of available water resources on a country scale. The surface water graphic divides the country into surface water regions, based on water quantities available. The ground water graphic divides the country into regions with similar ground water characteristics.

In addition to assisting the military planner, this assessment can aid the host nation by highlighting its critical need areas, which in turn serves to support potential water resources development, preservation and enhancement funding programs. Highlighted deficiencies include the damaged sea defense system, the deterioration of the drainage and irrigation systems, insufficient hydrologic data, lack of wastewater treatment plants and discharge-effluent laws, and the lack of hydropower. Watershed management plans should be enacted to control deforestation and to manage water resources. Ground water supplies most of the potable water for the country, because the surface water is used for agriculture and industry and is often contaminated. Long-term studies of the aquifers are recommended, particularly since ground water is being relied upon to supply more of the domestic water supply.

II. Country Profile

A. Geography

Guyana, with its 215,000 square kilometers of territory, is similar in size to the U.S. state of Idaho. It is in northeastern South America and shares a border with Suriname to the east, Brazil to the south and west, Venezuela to the west, and has a 459-kilometer Atlantic coastline to the north. The administrative divisions are divided into 10 primary regions. See figures 1 and 2 for general geographic information.

Guyana is divided into five major geographical regions: the coastal lowlands, the interior plains, the western highlands, the southern uplands, and the southwest savannah. (See figure C-1.)

Figure 2. Vicinity Map

The coastal lowlands region, which has about 90 percent of the country's total population, occupies about 10 percent of the country. The region varies from about 8 to 65 kilometers in width and is mostly below sea level. The normal range between low and high tide is about 3 meters. Most of the land, therefore, is subject to flooding (particularly sea invasion) especially during the wet seasons from April to August and November to January and during high tides. Elevations are extremely low with many areas below sea level. Other areas are manmade and built-up to raise them above the surrounding streams and the Atlantic Ocean. This region consists of low-lying plains along the coast formed primarily by the deposition of alluvial sediments from rivers flowing into the Atlantic Ocean. This strip of rich alluvial soil provides most of the agricultural production in the country. An elaborate system of sea defenses, along with irrigation and drainage canals, is required to protect the area from flooding.

The interior plains region, comprising about 35 percent of the country, extends east to west immediately south of the coastal lowlands. This region is an undulating expanse of white and brown sands covered with scrublands and hardwood forests that rises to elevations of about 120 meters. Precipitation in the interior plains provides the primary ground water recharge for the coastal lowlands. This region is dissected by rivers and perennial streams draining from the uplands and highlands.

The western highlands region covers about 15 percent of the country and is located in the westernmost part along the borders with Brazil and Venezuela. This region has rugged igneous and metamorphic mountains that are densely forested and virtually inaccessible. It is a dissected upland with steep tabular hills and mountains cut by deep gorges. Rivers are fast-flowing within deeply dissected terrain, creating deep gorges and waterfalls.

The southern uplands region covers about 30 percent of the country and is in the southernmost part, bordered by Brazil and Suriname. This region consists of four mountain ranges with elevations of 300 to greater than 1,200 meters. Access to these forested ranges is very limited.

The southwest savannah region, also known as the Rupununi Savannahs, is in the southwest along the border with Brazil and covers about 10 percent of the country. This region has rolling sedimentary hills with open grasslands and sparse trees and is mainly used for cattle ranching. During the dry seasons, the streams have very low flows and some become dry. The major river is the Rupununi River, which dissects the region. The Ireng River and Takutu River form the western border, shared with Brazil.

The road network within the country is limited with most all-weather roads along the coast. About 700 kilometers (430 miles) of paved roads exist in the country with a total road network of 2,350 kilometers (1,459 miles). Within the interior, travel is hindered by topography, river rapids and waterfalls, dense tropical forests, and lack of roads. Only one route leads inland from Georgetown through the interior to the town of Lethem on the Brazilian border, which is passable using four-wheel-drive vehicles.

B. Population

Per the 1996 census, Guyana has a population of 746,000, with more than 90 percent residing in the 3 to 15 kilometer-wide coastal plain that extends from the Courantyne River in the east to the Pomeroon River in the west. As a result, the narrow band of coast has a population density of more than 700 per square kilometer, while vast areas of the interior are virtually uninhabited. As of 1997, due to a high rate of emigration, Guyana has had a growth rate of -0.78 percent.

Georgetown, the capital and principal port, has a population of over 200,000. Other small-populated centers include the port of New Amsterdam with 25,000 inhabitants, and the mining community of Linden with 35,000 inhabitants.

C. Economy

Agriculture, mainly sugar and rice, and mining are the most important sectors of the economy, accounting for 75 percent of export earnings. Most of the agricultural production occurs in the coastal plain, which is frequently flooded due to the damaged sea defense system. The country is not self-sufficient in foodstuffs. High-priority demands for imports include wheat, vegetable oils, and animal products. Potential exists for the development of timber and fishing industries, but care must be taken not to exploit these resources.

Bauxite and gold are mined in the country, with gold recently becoming the second most valuable export after sugar.

Recent privatization of many government-owned industries has created a more favorable atmosphere for business initiative, which has led to a positive economic growth rate in the 1990s after 15 years of decline. The country has abundant natural resources including a wide range of minerals, vast stretches of tropical forests, extensive areas of fertile agricultural lands, and many rivers and waterfalls with considerable hydroelectric potential.

D. Flood Control

Inland of the coastal areas are irrigation water storage impoundments operated by the conservancies. The main purpose of the impoundments is irrigation water storage, but some flood protection is offered. Lack of maintenance has reduced the effectiveness of these impoundments, which has increased the potential for flooding.

E. Sea Defenses

Most of the original sea defenses were constructed by the Dutch in the 18th century, and consisted mainly of massive concrete seawalls on the Atlantic coast, designed to protect the densely-inhabited coastal plains. Through the years, more concrete seawalls, earthen embankments, canals, pumping stations, and drainage outfall sluices have been added to the system. Coastal processes over time, however, have severely damaged the sea defenses. The country has accomplished countless repairs to the seawall, from patching with loose stone or gabion structures to upgrading the massive concrete seawalls. Lack of maintenance has caused breaches in the dikes, resulting in occasional flooding of the coastal plains.

Most of the population lives and most of the agricultural production occurs in the narrow, flat coastal lowlands paralleling the northern coast, much of which is below sea level. The elaborate system of sea defenses is designed to keep the area as dry as possible, but periods of prolonged inundation occur due to disrepair. The normal range between low and high tide is about 3 meters, so without the sea defenses, much of this valuable agricultural land would be under water during the two high tides that occur each day.

The UASCE Mobile District conducted two studies of Guyana’s sea defenses in September 1994 and February 1997. Contact the individuals listed in the Preface for further information on these studies or a copy of the reports.

III. Current Uses of Water Resources

A. Water Supply

Guyana has abundant surface and ground water supplies near all populated centers. Both surface and ground water resources are relied upon for water supply requirements. Heavy amounts of precipitation provide high amounts of surface runoff and ground water recharge. Most of the domestic water supply comes from ground water resources, while most of the water supply for agriculture (sugarcane and rice) and industry comes from surface water.

Sewage systems in the urban areas are inadequate to nonexistent with minimal purification of water via filtration and chlorination, which occurs only in Georgetown when supplies are available and operational. The rest of the country uses septic tanks. Water distribution systems within Georgetown are poorly maintained and unreliable, forcing most residents to use individual cisterns. Canals throughout Georgetown are sources of water, but they also serve as sewers and are usually laden with agricultural and biological contamination and solid wastes.

1. Domestic Uses and Needs

About 90 percent of the domestic water supply comes from ground water sources, and the remaining 10 percent from surface water. The Georgetown Sewerage and Water Commission (GSWC) provides the water supply for the capital of Georgetown. This agency is responsible for the supply, treatment, and distribution of domestic and industrial water service within the city. Individual landowners use rooftop catchment systems with cisterns as a secondary water supply source. Georgetown has a demand of 20 million gallons per day with about 8 million being furnished from surface water and 12 million from ground water. Surface water is supplied by the East Demerara River Water Conservancy. Domestic water supply has third priority for use of the surface water supplied by the conservancy, so in periods of short supply, irrigation and transportation demands must be met first, and any excess water can then be used for domestic supply. This has led the GSWC to look to ground water for all future needs and as a replacement for surface water supplies.

The Guyana Water Authority (GUYWA) has the responsibility for domestic water supply for the rest of the country. Since almost all the population lives along the coast in numerous autonomous villages and communities, the water supply is furnished by a series of wells drilled along the coast.

GSWC is responsible for the drilling and maintenance of wells in Georgetown. Outside the Georgetown city limits, all water well drilling must be authorized by GUYWA, which provides most of the well drilling in the country. Drillers must be registered with GUYWA, and nongovernment contractors must obtain drilling permits from GUYWA before drilling a well. GUYWA also maintains data on most of the wells and available documents indicate that 603 drilled wells currently exist in the country. Another government agency, the Hydro-Meteorological Service, keeps historical reports on water wells and ground water data.

2. Industrial Uses and Needs

Industrial water supply comes from both surface and ground water. Approximately 40 percent of the ground water supply is for industrial uses and needs. In the future, more of the water supply for industry will come from ground water due to the declining supply of surface water. The predominant industrial use of water is the mining industry. Gold mining is done by hydraulic dredging of the rivers, and uses river water to wash the dredged material to extract the gold.

3. Agricultural Uses and Needs

The main agricultural crops are sugarcane and rice, which require intensive irrigation. Along the coast, several conservancies supply water to agricultural lands using reservoirs, canals, and irrigation ditches (see Chapter IV, A, 2). Each major township along the coast has one conservancy with its own unique entity and governing body. The East Demerara River Water Conservancy supplies the agricultural water needs for the Georgetown area. It is south of the city, and water is gravity-fed to the surrounding agricultural fields.

These drainage and irrigation systems, once adequate, have deteriorated because of lack of maintenance and can no longer sufficiently provide crop irrigation. The lack of storage capacity has hindered agricultural production, reduced the flood control capacity of the impoundments, and restricted the use of the impounded water for domestic consumption.

B. Hydropower

There is no hydropower presently available, but significant potential exists. Development is limited because most of the sites are difficult to reach, and reliable estimates are lacking on the potential of many streams. Currently, several projects are in the planning, design, and construction phase under agreements with outside power companies. Completion of some of these projects could make the country self-sufficient in providing abundant low-cost power for development of industry, agriculture, and domestic needs.

C. Waterway Transportation

Inland waterways are used for transportation by the logging industry. The Amerindians, the native Indian population, also use the rivers for local transportation.

Approximately 6,000 kilometers of navigable waterways exist. The Berbice, Demerara, and Essequibo Rivers are navigable by oceangoing vessels for 150 kilometers, 100 kilometers, and 80 kilometers, respectively. Ports are in the towns of Bartica, Georgetown, Linden, New Amsterdam, and Parika.

D. Recreation

Although the country's abundant water resources include 276 waterfalls and 18 lakes, recreational opportunities are limited. The main recreation associated with water resources is Kaieteur Falls, one of the world's highest waterfalls. While the site is quite beautiful, it is very remote and accessible only by small plane.

Ecotourism is being developed within the country, promoting the vast wilds of its jungles and its many species of birds. However, limited access to the country's interior, even by boat, restricts the development of this natural resource.

IV. Existing Water Resources

Guyana is rich in water resources. In fact, an overabundance of water is of concern. Fresh surface water is abundant throughout the country. Near populated areas and industrial sites, surface water sources are probably contaminated. There are several sources of surface water contamination, some of which is generated by the mining industry.

The coastal aquifer system is the source of most of the country's ground water resources, with exploration concentrated near the population centers of the Atlantic coast. Access to water points beyond the coast is extremely difficult due to the lack of all-weather roads and the abundance of thick vegetation.

While abundant forest resources and forest utilization have minimal direct impact on water resources, there are two areas that raise concern. One concern is the improper disposal of sawmill wastes, which raises biochemical oxygen demand levels and endangers aquatic life in the rivers. The other concern is the over-harvesting of forests in the White Sands area, which is degrading the timber stands to such an extent that they cannot regenerate. In turn, the reduction in forest cover could affect the recharge of the aquifer that provides most of the potable water for the country.

A. Surface Water Resources

Guyana has an extensive network of rivers and streams that have many rapids and waterfalls, with an absence of naturally occurring lakes. Surface water (which is extracted from shallow reservoirs, streams, or drainage canals) is primarily used for agricultural and industrial purposes. Only about 10 percent of the country's drinking water comes from surface water. Guyana faces the typical water pollution problems of developing countries in tropical regions. Biological and chemical contamination of surface water varies in magnitude according to location but is increasing with population growth and land use demands.

Since the late 1960's, hydrologic data collection has decreased dramatically. When the stream gages broke, they were not repaired or replaced. Efforts are underway to install modern telemetric gages throughout the country.

Excess water is a major concern, especially in the coastal lowlands where the land surface is below sea level. The lower elevations of the country along the coast, where most of the population and the agriculture is located, are threatened by tidal flooding, especially during high spring tides. The coastal lowlands are drained of water through a series of canals. During low tide, the gates or kokers of these canals are opened to allow the water to drain into the adjacent rivers or into the Atlantic Ocean. Large-capacity pumps are also used at various sites to drain the canals. Short-term localized flooding is common when heavy rains coincide with high tide, forcing the influx of water out of the canal banks until the gates are opened again.

1. Precipitation and Climate

The climate is tropical with two wet and two dry seasons. Along the coastal lowlands region, rain falls an average of 200 days a year, with 50 percent of the average rainfall occurring from mid-April to mid-August. The second wet season is in December and January. The wet seasons begin in the western parts of the country and move to the east, ending with their retreat back to the west. Therefore, the wet seasons are longer in the west. Annual rainfall for the country varies from about 229 centimeters on the coast to as much as 356 centimeters in the rain forest areas. In the generally dry savannahs, the annual rainfall average is only 152 centimeters, and most rainfall occurs from April to May. The savannah in the southwest and the uplands in the south have only one wet season from April to August.

Most of the country is covered by dense tropical forest with savannahs on the coast and in the southwest. The majority of the population lives in the coastal lowlands where the northeast trade winds moderate the climate. Temperatures here range from 20 to 33 degrees Celsius (68 to 91 degrees Fahrenheit), while temperatures in the interior regions range from 16 to 39 degrees Celsius (61 to 102 degrees Fahrenheit). Heavy precipitation provides large amounts of surface runoff, creating very high stream density (the ratio of streams per surface area), and where conducive, ground water recharge.

Guyana is not susceptible to hurricanes, tornadoes, earthquakes, or volcanoes. Although the rains are sometimes delayed, prolonged or severe droughts are rare.

2. Conservancies

Along the coast, several conservancies are set up to provide a consistent water supply to agricultural lands by means of canals and irrigation ditches (also see Chapter III, A, 3). Conservancies are shallow reservoirs of varying sizes, fed by streams and canals, offering a consistent supply of water year-round and some flood control. Each of the major townships along the coast has a conservancy, and each conservancy is governed by a board of commissioners. The water is fresh entering the canals and irrigation ditches but becomes more brackish as residence time increases. The outlets of the canals and irrigation ditches are brackish because they mix with the Atlantic Ocean and with the brackish to saline water in river mouths.

These drainage and irrigation systems, once adequate, have deteriorated because of lack of maintenance. The Government has initiated a major rehabilitation program to bring the drainage and irrigation systems back to full operating capacity. A new Drainage and Irrigation Board will oversee the development including the financing for the operation and maintenance of the systems.

3. Rivers and Basins

Rivers generally drain from the western highlands region and from the southern uplands region north to the coast. Smaller rivers originate in the interior plains region and flow northward to the coast or to primary streams. A few minor Amazon tributaries flow southwest out of the country and are part of the Amazon watershed. The country has four principal rivers–the Courantyne River bordering Suriname, the Berbice River, the Demerara River, and the Essequibo River. The Essequibo River forms the country's largest river system, and its drainage basin encompasses most of the country. It flows through the entire length of the country from the southern border to the Atlantic Ocean. Its major tributaries are the Cuyuni, the Mazaruni, the Potaro, and the Rupununi Rivers. Tidal influences can extend as far as 64 kilometers to 80 kilometers (40 to 50 miles) upstream on the four major rivers. Table 1 contains information for selected rivers.

Guyana has 14 major drainage basins with six of the rivers forming part of the country's boundary (see figure C-1). While these rivers provide abundant surface water resources, there are marked seasonal differences in the flows. Dense tropical vegetation contributes to a high rate of infiltration that sustains a continuous discharge to most rivers. Table 2 shows the average monthly discharge for the Essequibo River. The July discharge is more than 7.5 times as high as the November discharge.

Table 1. Data for Selected Rivers

River Name	Gaging Station	Drainage Area (mi^2)	Maximum Daily Flow (cfs)	Minimum Daily Flow (cfs)	Mean Flow (annual discharge) (cfs)	Period of Record
Essequibo	**Plantain Island**	**25,700**	**283,000**	**5,130**	**78,570**	**1950-69**
Cuyuni	**Kamaria Falls**	**20,600**	**190,500**	**350**	**37,560**	**1946-68**
Mazaruni	**Apaikwa**	**5,420**	**92,150**	**1,500**	**25,990**	**1950-68**
Mazaruni	**Hillfoot**	**8,000**	**146,350**	**2,000**	**40,460**	**1961-68**
Potaro	**Kaieteur Falls**	**1,020**	**39,600**	**400**	**7,224**	**1950-68**
Potaro	**Tumatumari**	**2,395**	**78,550**	**1,550**	**18,427**	**1946-54**
Demerara	**Great Falls**	**950**	**18,100**	**150**	**2,585**	**1949-67**
Demerara	**Saka**	**1,560**	**15,790**	**410**	**3,938**	**1950-67**
Berbice	**Itabu Falls**	**1,970**	**14,740**	**60**	**1,412**	**1960-68**
Canje	**Reynold's Bridge**	**107**	**304**	**51**	**94**	**1969**

Table 2. Average Monthly Discharge in Cubic Meters per Second for Essequibo River at Plantain Island (1950–1966)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1,040	1,120	998	1,180	2,790	4,770	5,320	4,450	2,270	979	698	889

B. Ground Water Resources

Fresh ground water is the most reliable and important source of water for public use and is abundant along the coastal lowlands and foothills to the immediate south where most of the population resides. Throughout the country, nearly 60 percent of the ground water produced from drilled wells is used for domestic water supply. With a growing demand on surface water for agricultural and industrial needs, ground water is becoming an increasingly important water source.

Ground water exploration is concentrated in the towns and villages along the Atlantic coast, with only scattered wells in the interior. Because of the abundant surface water resources, sparse population, and lack of suitable aquifer-forming rock types, the interior of the country has only a limited number of wells. Access to water points along the coast is relatively easy by the existing road network. However, the lack of all-weather roads makes access to water points south of the coastal lowlands extremely difficult.

Although ground water is generally safer than untreated surface water supplies, many shallow aquifers are becoming biologically contaminated, primarily due to improper waste disposal. To understand how ground water hydrogeology works and where the most likely sources of water may be located, a short aquifer definition and aquifer characteristics are presented followed by specific country attributes.

1. Aquifer Definition and Characteristics

Ground water supplies are developed from aquifers, which are saturated beds or formations (individual or group), which yields water in sufficient quantities to be economically useful. To be an aquifer, a geologic formation must contain pores or open spaces (interstices) that are filled with water, and these interstices must be large enough to transmit water toward wells at a useful rate. An aquifer may be imagined as a huge natural reservoir or system of reservoirs in rock whose capacity is the total volume of interstices that are filled with water. Ground water may be found in one continuous body or in several distinct rock or sediment layers within the borehole, at any one location. It exists in many types of geologic environments, such as intergrain pores in unconsolidated sand and gravel, cooling fractures in basalts, solution cavities in limestone, and systematic joints and fractures in metamorphic and igneous rock, to name a few. Unfortunately, rock masses are rarely homogeneous, and adjacent rock types may vary significantly in their ability to hold water. In certain rock masses, such as some types of consolidated sediments and volcanic rock, water cannot flow, for the most part, through the mass; the only water flow sufficient to produce usable quantities of water may be through the fractures or joints in the rock. Therefore, if a borehole is drilled in a particular location and the underlying rock formation (bedrock) is too compact (consolidated with little or no primary permeability) to transmit water through the pore spaces and the bedrock is not fractured, then little or no water will be produced. On the other hand, if a borehole is drilled at a location where the bedrock is compact and the rock is highly fractured with water flowing through the fractures, then the borehole could yield sufficient water to be economically useful.

Since it is difficult or impossible to predict precise locations that will have fractures in the bedrock, photographic analysis can be employed to assist in selecting more suitable well site locations. Other methods are available but are generally more expensive. Geologists can use aerial photography in combination with other information sources to map lithology, faults, fracture traces, and other features, which aid in well site selection. In hard rock, those wells sited on fractures and especially on fracture intersections generally have the highest yields. Correctly locating a well on a fracture may not only make the difference between producing high versus low water yields, but potentially the difference between producing some water versus no water at all. On-site verification of probable fractures further increases the chances of siting successful wells.

Overall, the water table surface is analogous to but considerably flatter than the topography of the land surface. Ground water elevations are typically only slightly higher than the elevation of the nearest surface water body within the same drainage basin. Therefore, the depth to water is greatest near drainage divides and in areas of high relief. During the dry season, the water table drops significantly and may be marked by the drying up of many smaller surface water bodies fed by ground water. The drop can be estimated based on the land elevation, on the distance from the nearest perennial stream or lake, and on the permeability of the aquifer. Areas that have the largest drop in the water table during the dry season are those that are high in elevation far from perennial streams and consisting of fractured material. In general, some of these conditions can be applied to calculate the amount of drawdown to be expected when wells are pumped.

2. Guyana Hydrogeology

The most important aquifers are in the unconsolidated, poorly sorted deltaic sands that underlie the coastal lowlands. The remaining aquifers are primarily in the igneous and metamorphic rocks of the Guyana Shield, which is mostly composed of Precambrian rocks. Other important aquifers are in unconsolidated sands and in other volcanic deposits. (see figure C-2 and Table C-2 for more details.) The coastal aquifers supply water for the 90 percent of the population that reside in the coastal lowlands region, with surface water supplying the remaining 10 percent. See figure 3 for a geologic cross section in the Georgetown area.

The coastal aquifer system, a series of three separate but hydrogeologically connected aquifers, has been providing water for the coastal inhabitants of the country for the last century. A relatively small area in the northwestern corner of the country contains brackish to saline water, and saltwater intrusion is becoming a concern in the eastern coastal lowlands. Ground water is locally plentiful from scattered sedimentary and volcanic deposits in the southern and western regions. Fresh ground water is scarce to lacking in the central mountainous area known as the Guyana Shield, where only fractures and small alluvial deposits produce water.

a. Coastal Aquifer System

Large quantities of fresh water are available from the coastal aquifer system. This system occupies a subsurface area of about 20,000 square kilometers, extending about 250 kilometers along the Atlantic coast and 40 to 150 kilometers inland. Sediments reach a thickness of 1,800 meters onshore and become progressively thicker offshore and toward the east. The coastal aquifer system is composed of three connected but hydrogeologically distinct aquifers. Overlying layers of clays confine the lower two aquifers, protecting them from contamination by overlying sources. The three aquifers are named, from upper to lower, the Upper Sands, the A Sand, and the B Sand, with each capable of yielding large amounts of water.

The Upper Sands aquifer is 30 to 60 meters deep and ranges in thickness from 15 to 120 meters; it is the shallowest of the three aquifers of the coastal aquifer system. In Georgetown in 1831, this was the initial aquifer developed for water supply. However, due to a high iron content (greater than 5 milligrams per liter) and brackish water (total dissolved solids greater than 1,200 milligrams per liter), the aquifer was never fully exploited and withdrawals ceased in 1913. The water from this aquifer becomes more saline toward the coast. The aquifer is composed of quartz grains, which represent former beach dune deposits. Within 15 kilometers of the coast, ground water in this formation is confined by the Demerara Clay, a marine clay. From 15 to 35 kilometers inland to the outcrop of the White Sands Formation, the older Coropina Formation, also a marine clay, acts

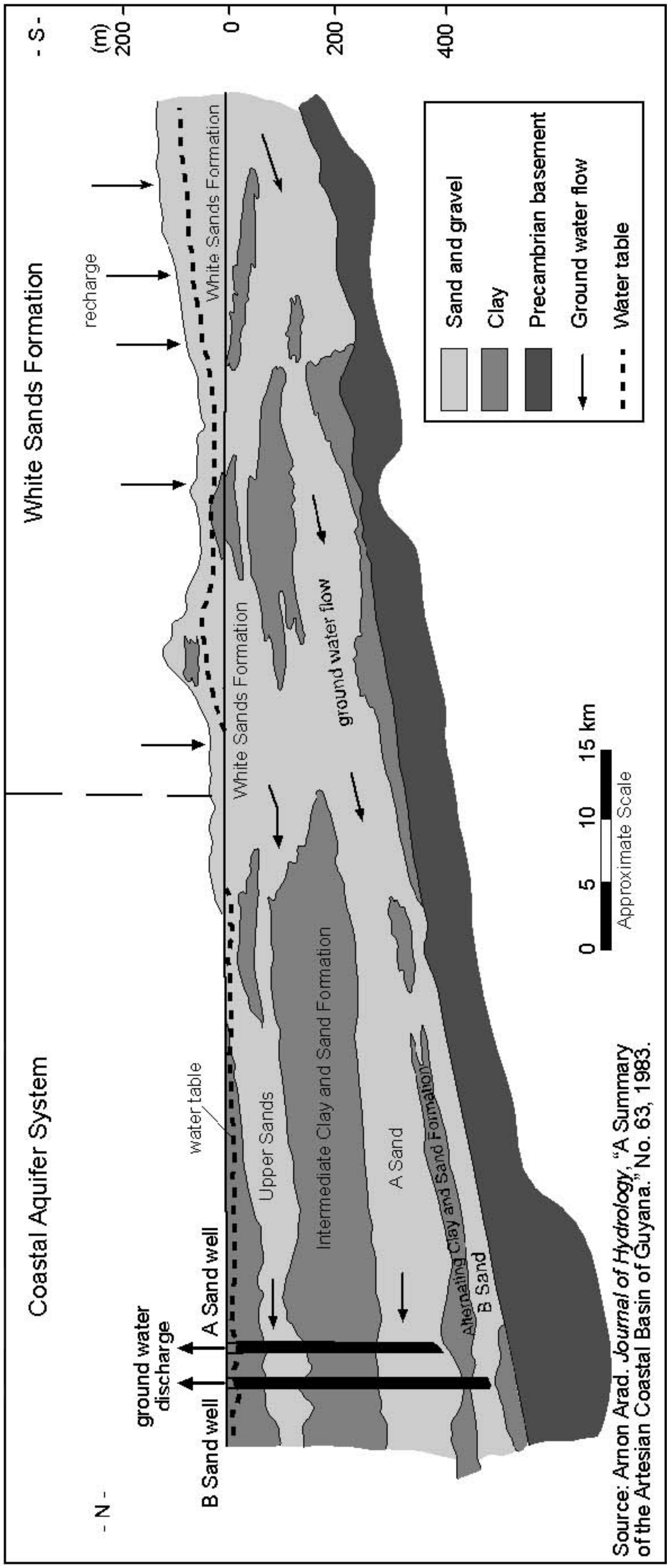

Figure 3. Geologic Cross Section in the Georgetown Area

as the confining unit. These confining clays have an average thickness of 45 meters. Thickness of the Upper Sands unit ranges from about 15 meters in the Georgetown area to 90 meters near the Courantyne River in the east. This unit crops out and is recharged through the White Sands Formation, 35 kilometers south of Georgetown.

The A Sand aquifer was first developed in 1913 and is now considered the principal water source for Georgetown and the coastal lowlands region. The Intermediate Clay Formation, which is about 90 meters thick and composed of clay and shale, acts as an impermeable barrier between the Upper Sands and the A Sand aquifers. The A Sand aquifer is composed of quartz sand and fine gravel, and ranges from 150 to 215 meters deep and 12 to 27 meters thick. In general, the aquifer increases in thickness and depth southeastward from the town of Enterprise to the town of Berbice. From Berbice to the Courantyne River, the A Sand aquifer decreases in thickness and depth. This aquifer yields between 4,000 and 40,000 liters per minute year-round. The quality of water withdrawn from this aquifer is good with a low chloride content; however, its high carbon dioxide and iron content can corrode ferrous and cement-based materials, with the excessive iron requiring treatment. When this aquifer was first used, it had a piezometric head 4.5 meters above ground level. By 1993, dewatering of this aquifer caused the head to fall to 14 meters below ground level.

The B Sand aquifer lies below the Upper Sands and the A Sand aquifers at depths of 350 to 800 meters and varies in thickness from 15 to 60 meters. The 65- to 130-meter-thick Alternating Clay and Sand Formation separates the A Sand and B Sand aquifers. While the B Sand is not exploited to the extent of the A Sand aquifer, it has yields of 4,000 to 40,000 liters per minute year-round. The water is fresh with no elevated levels of iron or chloride; however, it has a trace of hydrogen sulfide with temperatures up to 40.5 degrees Celsius (105 degrees Fahrenheit). This aquifer, which was first used for domestic water in 1962, is composed of angular quartz sand and shale with gravel. Heads of this aquifer exceed those of the A Sand. From the Georgetown area, this aquifer thins toward the east in the central part of the coastal lowlands where it becomes almost undetectable. Due to the lack of data, no recharge area has been definitively determined for the B Sand, but most studies indicate that the B Sand may be recharged by infiltration of precipitation in the White Sands Formation.

b. <u>Other Aquifers</u>

The White Sands Formation, located in the southern coastal lowlands region and northern interior plains region, yields moderate to large quantities of fresh water that are available from unconsolidated sand and sandstone deposits at depths of less than 30 meters. This formation is centered around the town of Linden. The level of total dissolved solids steadily increases toward the coast as the residence time and mineralization of the water increases. Farther inland in the northern savannahs of the Rupununi, the Takutu Sandstone Formation serves as an aquifer. This formation is composed of cross-bedded sandstones with siltstones and shales, and covers an area of about 5,200 square kilometers. Yields from the Takutu Sandstone Formation are moderate and the water is fresh.

In the western part of the country in the vicinity of the Merume Mountains, small to large quantities of fresh water can be obtained from volcanic ash, tuff, breccia, sand, sandstones, conglomerates, shales, and diabase dikes of the Roraima Group. These deposits are primarily composed of conglomerates and sandstones. Depth to ground water varies from 10 to 300 meters. Due to the low permeability of this aquifer, the most productive zones for ground water are the fractures. Little information exists on the ground water resources of this aquifer. Reports show scattered springs that produce very small to small quantities of fresh water.

In scattered locations throughout the interior, small to moderate quantities of fresh water are available from granites, gneisses, and sand deposits from various formations collectively known as the Trans-Amazonian Granitoids. These rocks, scattered throughout the country, are generally intrusive igneous plutons of granite and the associated contact metamorphic units. Water is generally only available from fracture zones. Depths to the water table vary with the season but range typically from 3 to 150 meters.

In the Kanuku Mountains of southern Guyana and in the Kauramembu Mountains in the west-central part of the country, meager to moderate quantities of fresh water are available from metamorphic rocks at depths ranging from 10 to 300 meters. These aquifers are composed of phyllites, schists, gneisses, and quartzites of the Brama-Mazaruni Supergroup. Ground water is generally available from fractures and bedding planes within the units. From aquifers located primarily in the central and southern parts of the country with the largest concentration in the headwaters of the Takutu River, meager to very small quantities of fresh water are available from igneous dikes and sills, tuffs, and lava flows. Depth to water ranges typically from 3 to 150 meters from fractures and joints within the rock units.

In the northwestern coastal region bordering the Waini River, large quantities of brackish to saline water are available from unconsolidated clay and sand deposits. Depth to water is generally between 3 and 30 meters. These deposits are alternating layers of Quaternary alluvial gravel, sand, and clay found in a marsh environment. Access to this area is limited by standing water and a lack of roads. This region is generally not considered for ground water exploration due to tidal flooding and continuous saturation.

C. Water Quality

The quality of surface water is a growing concern, with biological and chemical contamination most prevalent along the coast. Sewage systems within Georgetown are inadequate with disposal into the Atlantic Ocean. Periods during the wet and dry seasons are more susceptible for inducing contamination; open-ditch sewers and septic tanks may flood during the wet seasons, and during dry seasons, there may be insufficient flow to flush and dilute the contaminants.

Except for brackish or saline ground water near the Atlantic coast, ground water is suitable for most uses. Biological and chemical contamination of ground water is more common near populated areas and in the shallow aquifers.

Mining is an important industry in Guyana, but it is also a major source of surface and ground water contamination and degradation of rivers and streams. Dredging and other types of mining operations cause hydrocarbons to be released and increase sediment loading in rivers and streams. Improper disposal of sawmill wastes is another major concern, which raises biochemical oxygen demand levels.

1. Surface Water Quality

In Georgetown and in populated areas of the coastal lowlands, surface water contamination occurs from inadequate waste disposal and from chemicals used in the production of rice and sugarcane. Contamination of surface water, if not monitored properly, could develop into a major health hazard. Chemical contamination of surface water occurs primarily near manufacturing areas, especially along major rivers within mining districts. Commonly mined minerals are bauxite, gold, diamonds, and manganese. Contaminant of concern in bauxite production is caustic soda (sodium hydroxide). Contaminants of concern in gold production are cyanide, sulfuric acid, hydrochloric acid, and mercury. Mercury is used in extracting gold in small mining operations, with arsenic generated as a by-product. The Essequibo, the Mazaruni, the Cuyuni, the Barima, and the Barama Rivers and associated tributaries are probably polluted by these chemicals. Documented cases of mercury spills into interior streams from gold-mining operations have led to strict environmental protection practices. Cyanide is used in the processing of gold from hard rock. Cyanide contamination from gold production operations has occurred more than once in the Omai and Essequibo Rivers. The Demerara River, the Upper Berbice, the Upper Canje, and associated tributaries may be chemically polluted from caustic soda (sodium hydroxide) used in the production of bauxite. The presence of chemicals to control aquatic weeds in the canals is also a serious problem in the coastal lowlands.

2. Ground Water Quality

Biological contamination of shallow aquifers by pathogens due to improper disposal of animal and human wastes is a common problem. Chemical contamination is primarily related to the use of fertilizers in the sugarcane and rice fields of the coastal lowlands. The Upper Sands aquifer, which is not normally used for water supply, is highly susceptible to biological and chemical contamination, particularly in the Georgetown area, and the water is generally brackish to saline. Overuse of aquifers in coastal areas may result in saltwater intrusion. During the dry seasons in the interior, shallow wells may temporarily go dry until sufficient aquifer recharge occurs.

Ground water is generally not contaminated along the coast in the A Sand and B Sand aquifers. The Upper Sands and A Sand aquifers have elevated iron contents, and the B Sand has elevated temperatures and a hydrogen sulfide odor.

While data concerning the deeper A and B Sand aquifers indicate that they are confined, contamination is still possible from recharge areas or improperly constructed wells. Contamination plumes generally follow the flow direction and slope of the ground water, making areas downslope of the populated sites susceptible. Fracture systems typically transport contamination in a variety of directions very quickly and not necessarily downslope.

V. Water Resources Regional Summary

A. Introduction

This chapter summarizes the water resources of Guyana, which can be useful to water planners as an overview of the available water resources. Figure C-1, Surface Water Resources, divides the country into surface water categories, identified as map units 1 through 6. Table C-1, which complements figure C-1, details the quality, quantity, and seasonality of significant water features within each map unit, and describes accessibility to these water sources. Figure C-2, Ground Water Resources, divides the country into categories with similar ground water characteristics, identified as map units 1 through 7. Table C-2, which complements figure C-2, details the predominant ground water characteristics for each map unit, such as aquifer names, materials and thickness, depth to water, yields, and water quality. A summary of the water resources of each administrative region is provided, based mainly on these figures and tables.

B. Water Conditions by Map Unit

Figure C-1 divides the country into six map unit categories based on surface water quality and quantity and divides the country into five physiographic regions (labeled I, II, III, IV, and V). A physiographic region is based on surface water characteristics and may contain more than one river basin. These five physiographic regions cross several administrative boundaries.

Map unit 1 depicts areas where fresh surface water is perennially plentiful in enormous quantities throughout the year from perennial rivers and streams. Map unit 2 depicts areas where fresh surface water is perennially plentiful in enormous quantities from April through August and November through January from rivers and streams draining the interior plains and western highlands. Large to very large quantities are available from map unit 2 during the rest of the year. Map unit 3 depicts areas where fresh surface water is seasonally plentiful in large quantities from April through August and November through January from perennial and intermittent streams in the coastal lowlands, the interior plains, and a small area in the western highlands. Small to moderate quantities are available during the rest of the year. Map unit 4 depicts areas where fresh surface water is seasonally plentiful in large quantities from April through August from perennial and intermittent streams in the southern uplands. Meager to moderate quantities are available during the rest of the year. Map unit 5 depicts areas where fresh surface water is seasonally plentiful in moderate to large quantities from April through August from perennial and intermittent streams in the southwest savannahs and from tributaries of the Amazon River. Meager to small quantities are available during the rest of the year from perennial streams, while the intermittent streams generally have no discharge. Map unit 6 depicts areas where fresh water is scarce or lacking, with large to enormous quantities of brackish to saline water perennially available from tidal-influenced rivers, streams, coastal marshes, mangrove swamps, and tidal lowlands.

Figure C-2 divides the country into seven map unit categories based on water quality, quantity, and aquifer characteristics. Map unit 1 depicts areas where fresh ground water is generally plentiful in large quantities from marine sands and clays in the coastal lowlands. Map unit 2 depicts areas where fresh ground water is generally plentiful in moderate to large quantities from unconsolidated sands and sandstones in the coastal lowlands, interior plains, and the southwest savannah. Map unit 3 depicts areas where fresh ground water is locally plentiful in small to large quantities from volcanic deposits of ash, tuff, and conglomerate, primarily in the western highlands. Map unit 4 depicts areas where fresh ground water is locally plentiful in small to moderate quantities from fractured granites, mudstones, gravels, and sands located in scattered deposits throughout the country. Map unit 5 depicts areas where fresh ground water is scarce or lacking in meager to moderate quantities from igneous and metamorphic rocks in scattered deposits throughout the country. Map unit 6 depicts areas where fresh ground water is scarce or lacking in meager to very small quantities from igneous dikes and andesitic flows in the western highlands, southern uplands and the southwest savannah. Map unit 7 depicts areas where fresh ground water is scarce or lacking with large quantities of brackish to saline water available from unconsolidated sand and clay in the northwest coastal lowlands.

Surface water and ground water quantity and quality for each administrative region are described by the following terms:

Quantitative Terms:

Enormous	= >400,000 liters per minute (100,000 gallons per minute)
Very large	= >40,000 to 400,000 liters per minute (10,000 to 100,000 gallons per minute)
Large	= >4,000 to 40,000 liters per minute (1,000 to 10,000 gallons per minute)
Moderate	= >400 to 4,000 liters per minute (100 to 1,000 gallons per minute)
Small	= >40 to 400 liters per minute (10 to 100 gallons per minute)
Very small	= >4 to 40 liters per minute (1 to 10 gallons per minute)
Meager	= $\leq$4 liters per minute (1 gallon per minute)

Qualitative Terms:

Fresh water	= maximum total dissolved solids (TDS)* $\leq$1,000 milligrams per liter; maximum chlorides $\leq$600 milligrams per liter; and maximum sulfates $\leq$300 milligrams per liter
Brackish water	= maximum TDS* >1,000 milligrams per liter but $\leq$15,000 milligrams per liter
Saline water	= TDS* >15,000 milligrams per liter

*The sum of TDS is the concentration of minerals in water. Most of the dissolved minerals are inorganic salts also described as *salinity*. The World Health Organization guideline for the maximum recommended level of drinking water quality for TDS is 1,000 milligrams per liter. Fresh water quality does not mean that the water is readily potable; purification for biological and chemical contamination may still be required.

C. Water Conditions by Administrative Region

The following information was compiled for each administrative region from data contained in figures C-1 and C-2, and Tables C-1 and C-2. The write-up for each region consists of a general overview of the surface and ground water resources derived from a country scale overview. Locally, the conditions described may differ. Site-specific reconnaissance may reveal different water conditions than those indicated by the map unit categories. Additional information, therefore, is necessary to adequately describe the water resources of a particular region. The regional summaries should be used in conjunction with figures C-1 and C-2.

Barima-Waini Region

Area and relative size: 19,350 km^2 (9 percent of country)

Location: The western border of this region is shared with Venezuela, and the Atlantic Ocean borders to the north. The coastal area is sparsely populated, unlike the remainder of the Guyana coast.

Surface Water

The coastal lowlands physiographic region occupies about 40 percent of the area in this region and has brackish to saline water available from tidal-influenced rivers and streams, coastal marshes, mangrove swamps and tidal lowlands, as depicted by map unit 6. The rest of the region, south of the coastal lowlands, lies in the interior plains physiographic region, as depicted by map unit 2, where large to enormous quantities of fresh water are available from April through August and November through January with large to very large quantities available the rest of the year.

Ground Water

About 40 percent of the region lies in map unit 1, extending from the Atlantic Ocean in the northeast to the border with Venezuela in the west, where large quantities of fresh water are available from the coastal aquifer system. Ground water exploration during military exercises is recommended in this area, but accessibility may be a problem. Ground water exploration during military exercises is not recommended in the rest of the region, which is in the interior plains.

Cuyuni-Mazaruni Region

Area and relative size: 43,000 km^2 (20 percent of country)

Location: This region, which is sparsely populated, is in the western part, lying in the interior plains and western highlands, with Venezuela bordering on the west.

Surface Water

Map unit 1 occupies about 25 percent of the region and is found along the Cuyuni, Mazaruni, and the Essequibo Rivers, where enormous quantities of fresh water are available year-round. Tiboku Falls, as well as several water quality and gaging stations, are located on the Mazaruni River. There are also a few gaging stations on the Cuyuni River. About 65 percent of the region lies within map unit 2, where enormous quantities of fresh water are available from April through August and November through January with large to very large quantities of fresh water available the rest of the year.

Ground Water

Ground water exploration during military exercises is not recommended in most of the region which lies within map units 3, 4, 5, and 6, where access is difficult or impossible due to lack of roads and steep terrain. Map unit 2, consisting of the White Sands Formation, occupies about 10 percent of the region in the northeast. Moderate to large quantities of fresh water are available from this aquifer, but difficult access due to lack of roads may prohibit ground water exploration.

Demerara-Mahaica Region

Area and relative size: 2,150 km^2 (1 percent of country)

Location: This region contains the national capital of Georgetown on the Atlantic coast and most the country's industry. The Demerara River is in the western part of the region near the border.

Surface Water

Fresh water is available in small to large quantities year-round from streams, tributaries, canals, and ditches in about 40 percent of the region in the north, as depicted by map unit 3. Along the coast and along the Demerara and Mahaica Rivers, large to enormous quantities of brackish water are available year-round as depicted by map unit 6, which covers about 30 percent of the region. Georgetown lies in this map unit on the Atlantic coast. Map unit 1 occupies about 10 percent of the region in the southwest along the Demerara River where enormous quantities of fresh water are available year-round. Map unit 2 occupies about 20 percent of the region in the southeast, where enormous quantities of fresh water are available from April through August and November through January with large to very large quantities available the rest of the year.

Ground Water

This region is rich in ground water resources, and ground water exploration is recommended in most of the department except in the southern half where accessibility may be a problem in the map unit 2 areas. Map unit 1 lies in the coastal lowlands where the coastal aquifer system is located. The national capital of Georgetown lies in this map unit. The greatest amount of ground water development of the coastal aquifer system is in the vicinity of Georgetown. The best aquifer in the system is the A Sand which is located at depths ranging from 150 to 215 meters. Map unit 2, the White Sands Formation, lies south of the coastal lowlands. This aquifer yields moderate to large quantities of fresh water, but difficult access to water points may prohibit ground water exploration. There are few known existing wells in this aquifer.

East Berbice-Corentyne Region

Area and relative size: 40,850 km^2 (19 percent of country)

Location: This region occupies the entire eastern part of the country bordering Suriname. The Courantyne River forms the eastern border of the region, which is also the boundary between Guyana and Suriname.

Surface Water

Map unit 1 occupies about 20 percent of the region and lies along the Courantyne, Canje, and New Rivers. Enormous quantities of fresh water are available year-round from these perennial rivers. Map unit 2 occupies about 40 percent of the region and is located predominantly in the interior plains, where enormous quantities of fresh water are available from April through August and November through January, with large to very large quantities available the rest of the year. Map unit 4 occupies about 30 percent of the region in the southernmost part in the southern uplands where large quantities of fresh water are available from April through August, with meager to moderate quantities available the rest of the year.

Ground Water

Most of the population centers are located in map unit 1 of the coastal lowlands in the northernmost part of the region. Map unit 1 occupies about 10 percent of the region where the coastal aquifer system is located. Numerous existing wells are in this area, and ground water exploration is recommended. The best aquifer in the system is the A Sand, which is located at depths ranging from 150 to 215 meters, with large quantities of fresh water available. The rest of the region, which is south of the coastal lowlands, is likely to be inaccessible due to lack of roads. Map unit 2, occupying about 10 percent of the region, outcrops south of map unit 1 and can be found along the Courantyne River as far south as the confluence of the Timehri and Courantyne Rivers. The White Sands Formation lies in map unit 2, which consists of unconsolidated sand that yields moderate to large quantities of fresh water. Ground water exploration in map unit 2 areas may be prohibited by difficult access due to lack of roads. Few wells are known to exist in this map unit.

Essequibo Islands - West Demerara Region

Area and relative size: 6,450 km^2 (3 percent of country)

Location: This is one of the more densely populated regions with the Atlantic Ocean bordering to the north. The Essequibo River flows through the center of this region, discharging into the Atlantic Ocean.

Surface Water

About 60 percent of the interior of this region lies in the interior plains and is occupied by map unit 2. Enormous quantities of fresh water are available from April through August and November through January from perennial rivers and streams with large to very large quantities of fresh water available the rest of the year. Along the Atlantic coast and the Essequibo River, large to enormous quantities of brackish to saline water are available year-round, as depicted by map unit 6, which occupies about 30 percent of the region, much of which lies in the coastal lowlands. The population centers of Enterprise, Leonora, Perika, and New Found Out are in map unit 6. Map unit 1, which occupies about 10 percent of the region, lies along the Demerara River in the south, where enormous quantities of water are available year-round.

Ground Water

This region has abundant ground water resources, particularly in the coastal lowlands, which cover about 40 percent of the region, as depicted by map unit 1. The coastal aquifer system is located here, where numerous wells exist particularly in the population centers of Perika, Enterprise, and Leonora. Ground water exploration during military exercises is recommended in this area. The A Sand is the best aquifer in the coastal aquifer system, located at depths ranging from 150 to 215 meters. Map unit 2 occupies about 40 percent of the region, inland of the map unit 1 areas. The White Sands Formation, located in map unit 2, yields moderate to large quantities of fresh water, but difficult access to water points may prohibit ground water exploration. Few wells are known to exist in this aquifer.

Mahaica-Berbice Region

Area and relative size: 4,300 km^2 (2 percent of country)

Location: This is one of the more densely populated regions, with the Atlantic Ocean bordering to the north. Many population centers are in this region along the coast.

Surface Water

Map unit 3 occupies about half of this region, which lies within the coastal lowlands physiographic region, where large quantities of fresh water are available from April through August and November through January. Along the coast and along the Demerara and Mahaica Rivers, large to enormous quantities of brackish water are available year-round as depicted by map unit 6, which covers about half of the region. The Mahaica, Mahaicony, and Abary Rivers lie in this map unit. Small to moderate quantities of fresh water are available the rest of the year. Along the coast, large to enormous quantities of brackish water are available year-round as depicted by map unit 6, which covers about 30 percent of the region.

Ground Water

Ground water exploration is recommended in most of this region, but difficult access due to lack of roads may prohibit ground water exploration in map unit 2 areas, located in the south. Map unit 1 occupies about 70 percent of the northernmost part of the region, including the coastal area and the population centers of Mahaica Village, Mahaicony, and Catherinas Lust. Many water wells are located in this area. The coastal aquifer system is located here, and the best aquifer of the system is the A Sand, located at depths ranging from 150 to 215 meters.

Pomeroon-Supenaam Region

Area and relative size: 6,450 km^2 (3 percent of country)

Location: This region is located on the west bank of the Essequibo River, with the Atlantic Ocean bordering to the north.

Surface Water

Map units 2 and 6 cover this region. About 75 percent of the interior part of the region lies in the interior plains and is occupied by map unit 2. Enormous quantities of fresh water are available from April through August and November through January from perennial rivers and streams such as Pomeroon and Supenaam Rivers. Large to very large quantities of fresh water are available the rest of the year. Map unit 6 lies in the coastal lowlands where brackish to saline water is available year-round from tidal-influenced rivers and streams, coastal marshes, mangrove swamps and tidal lowlands. The population centers of Suddie and Spring Garden on the Atlantic coast, and Charity on the Pomeroon River are located in this area.

Ground Water

Existing wells are limited to the coastal lowlands due to lack of roads, marshy terrain, and thick vegetation to the south. The coastal lowlands lie within map unit 1, which covers about 25 percent of the region, including the population centers of Suddie, Spring Garden, and Charity, where the coastal aquifer system is present. The A Sand is the best aquifer for ground water exploration in this area and is located at depths ranging from 150 to 215 meters. Ground water exploration during military exercises is recommended in this area.

The rest of the region lies in map units 2, 4, and 5 in the interior plains where accessibility may be difficult due to lack of roads. Map unit 2 occupies about 25 percent of the region in the southeast where fresh water is available from an unconsolidated sand aquifer known as the White Sands Formation. Moderate to large quantities of fresh water are available from this aquifer, except difficult access may prohibit ground water exploration. Few known wells exist in this aquifer.

Potaro-Siparuni Region

Area and relative size: 25,800 km^2 (12 percent of country)

Location: This sparsely populated region is in the west-central part of the country, lying mostly in the western highlands, with Brazil bordering to the west.

Surface Water

Map unit 1 occupies about 10 percent of the region and is found along the Essequibo and Potaro Rivers, where enormous quantities of fresh water are available year-round. Kaieteur Falls, one of the world's highest waterfalls, is located in this map unit on the Potaro River. The falls are, however, very remote and accessible only by small plane. Most of the region lies in map unit 2 where enormous quantities of water are available from April through August and November through January with large to very large quantities of fresh water available the rest of the year. Less than 20 percent of the region, which lies in the southwest savannah physiographic region, occupies map units 4 and 5. The Ireng River forms the western border of this region, which is shared with Brazil.

Ground Water

Ground water exploration during military exercises is not recommended in most of this region because fresh water is lacking or scarce. Access is difficult or impossible due to steep vegetated terrain and the lack of roads.

Upper Demerara-Berbice Region

Area and relative size: 15,050 km^2 (7 percent of country)

Location: This region is in the interior of the country. The Essequibo River flows through the westernmost part of the region.

Surface Water

This region lies in the interior plains. Map unit 1 occupies about 25 percent of the region and is found along the Essequibo, Demerara, and Berbice Rivers, where enormous quantities of fresh water are available year-round. Several water quality and gaging stations are located in this map unit. Map unit 2 occupies about 60 percent of the region where enormous quantities of fresh water are available from April through August and November through January with large to very large quantities available the rest of the year. A few gaging stations lie in this area. The rest of the region lies in map units 3 and 6.

Ground Water

Ground water exploration during military exercises is not recommended in most of this region because fresh water is lacking or scarce, or access is difficult or impossible due to steep vegetated terrain and lack of roads. Map unit 1, where ground water exploration is recommended, occupies about 5 percent of the region in the northeast where the coastal aquifer system is located north and east of the population center of Takama. The White Sands Formation, the map unit 2 aquifer, is centered around the town of Linden in the north. Accessibility to map unit 2 areas may be difficult, prohibiting ground water exploration.

Upper Takutu-Upper Essequibo Region

Area and relative size: 51,600 km^2 (24 percent of country)

Location: This sparsely populated region is in the southwestern part of the country, with Brazil bordering to the west and south.

Surface Water

Map unit 1 occupies about 20 percent of the region and is located along the Essequibo, Illiwa, Rupununi, and Kwitaro Rivers, where enormous quantities of fresh water are available year-round. In the east, King William Falls lies on the Essequibo River in map unit 1. About 40 percent of the region lies in map unit 4 in the southern uplands, where large quantities of fresh water are available from April through August, and meager to moderate quantities are available the rest of the year. The rest of the region lies in map units 2 and 5.

Ground Water

Ground water exploration during military exercises is not recommended in most of this region because fresh water is lacking or scarce. Access is difficult or impossible due to steep vegetated terrain and the lack of roads. Map unit 2 occupies about 15 percent of the region in the northwest. The aquifer in this map unit consists of sand and sandstones of the Takutu Sandstone Formation, which yields moderate quantities of fresh water. Small capacity wells in this aquifer are located in the area of Lethem, which is a population center on the Takutu River bordering Brazil.

VI. Recommendations

Almost all Government agencies, companies, and private individuals that were interviewed during the country visit expressed interest in technical assistance and support. They are keenly aware of the country's need to apply more resources to planning, development, and management of their water resources.

Repair and maintenance programs for the sea defenses are recommended due to the invasion of the sea in the coastal areas where the breaches occur. The sea invasions cause much damage to a large percentage of the inhabited region of the country, resulting in devastating consequences to the economic base of the country.

Since the major source of surface water contamination is from untreated domestic and industrial waste disposal, a large construction program for new wastewater treatment plants is recommended along with enforced laws on proper effluent treatment. While studies of the A Sand and B Sand aquifers exist, a comprehensive long-term study of the aquifers is recommended to evaluate the effects of increased pumpage, to determine their ability to provide more potable water, in view of the decline of potable surface water. Dependent on the results of the study, a large-scale ground water exploration program, beginning particularly in the areas of the best aquifers, would be beneficial, as most of the potable water supply for the country is from deeper wells and springs.

It is recommended that the Government continue the current rehabilitation program of the drainage and irrigation systems, which is being overseen by a new Drainage and Irrigation Board.

The following recommendations reflect a composite of the needs identified by the assessment team and Guyanese officials.

A. Basic Technical Training

Appropriate training is critical to the cost-effectiveness and success of any water resources management program. The initial investments required for training programs will more than earn reimbursements through savings in engineering practices. Examples of savings would be avoiding wasteful spending in bridge construction through prevention of over-design, which is excessive, or under-design, which requires replacements. Guyanese officials expressed an interest in the following recommended training:

1. Water Resources Management

The U.S. Army Corps of Engineers (USACE) can provide training, using several software programs on water resources management. The Corps' Hydrologic Engineering Center at Davis, California, and the Corps' Waterways Experiment Station at Vicksburg, Mississippi, developed these state-of-the-art programs. Included in the programs are data storage and management, planning, reservoir regulations, river hydraulics, statistical hydrology, surface water hydrology, and coastal design analysis.

2. Coastal Designs

In response to a special Mobile District report concerning the failure of some of the sea defense facilities, hydraulics engineers in Guyana have inquired about training in coastal design processes. The Mobile District can conduct associated training on a reimbursable basis. A request for this training should be directed through the U.S. Embassy. The Corps' software and training are also beneficial for evaluating simulations needed for hydropower designs.

3. Technical Exchanges

Proper analyses, such as benefit-to-cost studies and environmental assessments, are necessary to optimize the use of the country's water resources. Facts must be properly documented to enable enlightened decisions. Technical exchange and attendance at specialized seminars would introduce Guyana's engineers to strategies for developing resources.

B. Watershed Protection

A byproduct of the logging practices is the possible indiscriminate disposal of sawmill wastes, which raises biochemical oxygen demand levels and endangers aquatic life in the rivers. Shared expertise through training and technology transfers could provide alternative methods for disposal of these wastes. Overharvesting of forests in the White Sands area is also causing problems because the practice is degrading the timber stands, preventing them from regenerating. This in turn can affect the resupply of the A Sand aquifer, which provides most of the potable water for the country. The intent of a watershed or basin management plan is to achieve a comprehensive view of water and land resources problems within a watershed and identify opportunities and authorities to address such problems. Watershed planning is a systematic approach to evaluating alternate uses of the water and land resources to identify conflicts and trade-offs among competing uses such that informed decisions can be made when changes are contemplated. Such plans should include short-term measures (i.e., erosion stabilization, bridge protection, flood warning systems, small water supply systems), interim measures (flood control actions, sediment control programs, flood plain management, small reservoirs) and long-term measures (reforestation, large impoundment for flood control, hydropower, and water supply). Hydrologic information on the major rivers is lacking, particularly since the late 1960's. There is a critical need for additional river gages and the repair of broken ones. Sufficient hydrologic records are crucial to the development of watershed management plans and proper management of the water resources.

C. Coastal Zone Management

Most of the population lives in the coastal area that is protected by a sea defense system of seawalls and canals. Therefore, coastal erosion is a primary concern. Repairs and maintenance are very costly, and as a result, Guyana is unable to retain the system at its designed level of protection. The system is vulnerable to sudden failures of even small areas of the seawalls that could cause extensive damage to residences, businesses, and crops. A comprehensive coastal zone management program would facilitate the protection and development of the coastal areas

D. National Water Resources Management and Policy

Lack of coordination between GUYWA and GSWC in Georgetown has possibly created duplication of effort and lack of exchange of technical knowledge and data. Data are lacking on almost all aspects of water resources beyond the coastal plain. Shortage of funding has led to the loss of trained field personnel and to the cessation of water resources data collection. Even the limited data is not readily available to all agencies.

Benefits to be gained from improving the water resources management and policy, especially in the areas of drainage and irrigation, would be substantial. Since most of the country's agricultural production is dependent on the existing elaborate drainage and irrigation system, optimum use of this system is necessary to improve the agricultural economy. Broad goals should focus on public health, economic development, social well-being, and environmentally sustainable development. An established framework would produce national policy issues and management strategies. This would require an assessment of the purpose for various water resources projects, such as water supply, water quality, irrigation, drainage, navigation, hydropower, fish and wildlife. An in-country evaluation is needed to restructure the country's water resources management and to better define national interest and policy.

Listed below are generalized approaches for gradual improvement of the current water resources management system.

1. Formation of a Water Resources Council

Formation of a Water Resources Council at the national or international level would encourage information exchange and possibly shared organizational funding for common needs. The council should be made up of high-level executives from member entities. At the national level, candidate members would be heads of national offices and development corporation presidents. At the international level, candidate members would include the heads of organizations such as the U.S. Agency for International Development (USAID), the Cooperative for American Relief to Everywhere (CARE), and the European Economic Community (EEC). Each member could assign staff to help on special studies and evaluations. The focus should be on discussing water resources activities and on providing policy advice to Guyana's President. A fund should be established to solicit member nations or other entities to contribute to water resources development or interrelated needs. Good topographic mapping of the country, particularly of the coastal lowlands, development of a national data base for hydrology and hydraulics information, conservation of soil and water resources, and environmental enhancement could result from this combined funding effort.

2. Formation of Comprehensive Water Resources Evaluations

The objective of the evaluations would be to analyze all ongoing and proposed water resources activities in the country. Discussions are necessary with the literally hundreds of entities involved. These discussions should be followed with extensive field evaluations. After the field information is collected, the long and arduous task of research and analysis should begin. As a result, duplication will be eliminated, allowing for more cost-effective operations. The potential savings that could result from conducting a comprehensive evaluation of all water resources and interrelated activities are substantial.

3. Establishment of a National Clearinghouse

A national clearinghouse should be established to gather information from various national and international entities. A mailing list of all entities would have to be developed. Then, any organization involved in water resources development would have to forward their respective water resources proposals. Once the information is gathered, the clearinghouse would be responsible for mailing pertinent data to appropriate parties upon request. Because of the high expenses and the difficulties in obtaining cooperation from a variety of sources, success with a clearinghouse is not probable unless mandated by force of law.

4. Organization of National and International Meetings

National and international meetings encourage the exchange of information. Meetings can be excellent platforms for scientists, engineers, and water managers to exchange ideas, concepts, and proven water resources management experiences. However, the meetings should not be too theoretical. Long-range proposals are recommended, but some suggestions should be immediately implementable. A national gathering with selected international participation would be a good initial meeting. This meeting would also be a good forum to discuss other national water policy alternatives, such as water resources councils, comprehensive water resources evaluations, and national clearinghouses. The meeting should last from 3 to 7 days and be held in an easily accessible city, such as Georgetown. Subjects for topics and workshops should include: (a) national water policy issues, (b) water conservation, (c) coastal zone management, (d) major water resources projects either planned or being constructed, (e) experiments in changing crops, (f) reforestation, (g) soil erosion, (h) irrigation techniques, (i) well drilling, (j) water quality, (k) water treatment, and (l) hydropower.

5. Formation of Task Forces

The use of one of two types of task forces recommended is advised. The one type of task force requires leadership by a major national agency. Under this agency, task forces should be established to identify such national needs as (a) water laws, (b) education programs, (c) data bases for technical data, (d) surveys and mapping, and (e) programs for drainage and irrigation. Participants in these agency-led task forces should be members of various national and international organizations. The other type of task force would be the Water Resources Commission. This commission would identify the national needs, and would also make recommendations on water policy and the appropriate level of Federal involvement. These recommendations should be documented in a report by the commission. The commission would consist of three to six high-level officials appointed by the President for 1 to 3 years. Terms should be staggered for consistency and fresh approaches. These officials should have a blend of various backgrounds. Engineers, scientists, agricultural experts, university professors, politicians, economists, and geologists would be good candidates. This commission would need a small staff to manage details and prepare and disseminate reports. The commission should be host for a series of public meetings and/or use a format of requesting testimony from a wide spectrum of professionals, agencies, and the public. Input from various national and international agencies should also be solicited. The result could be a cost-free task force representing a variety of entities, especially if several committees and subcommittees could be formed to evaluate national water policies, water agency involvements, and other water resources needs.

E. Troop Exercise Opportunities

USSOUTHCOM currently provides assistance to Guyana through its Humanitarian Civic Assistance (HCA) exercises, which can include water well drilling. Water wells are sometimes drilled and used as water supply for troops during the exercise. Upon completion of the exercise, the successful wells are appropriately fitted and turned over to the communities for use as a water supply. Small surface impoundments should not be considered for water supply, because numerous impoundments exist for irrigation, and few suitable locations are available for new impoundments.

Guyana has hosted U.S. military water well exercises since the early 1990's. Water wells are the primary source of potable water for the country, so water well exercises will continue to be beneficial, as much of the surface water is not potable. The positive aspects of conducting well-drilling exercises include: providing potable water in areas where contaminated surface water may be the sole water supply, and providing training for U.S. military troops and Guyanese drillers. As part of the U.S. troop engineering exercises, the installation of small hand pump wells, especially in rural areas, could be of great benefit. These wells could be a source of safe potable water replacing contaminated surface water supplies in certain areas of the country. Well exercises in Georgetown should be coordinated with GSWC, while well exercises in the rest of the country should be coordinated with GUYWA.

Figure C-2 (with Table C-2) should be used by planners as a general guide to selecting favorable areas for water wells. Areas lying within map unit 1 would be good areas to consider for potential ground water exploration. Caution should be exercised if selecting areas lying within map units 2 through 7. More detailed analysis for selected areas would be needed prior to well site selection, to obtain detailed site-specific hydrogeological information for estimating the potential of successful ground water exploration.

VII. Summary

Given the rainfall, topography, and geological conditions, Guyana's water resources are probably adequate to meet domestic demands and to support continued growth in the agricultural and industrial sectors. Guyana lacks the economic resources to properly develop and maintain its water supply requirements. Contamination of surface waters from domestic and industrial wastes is a problem in some areas. The ground water aquifers are generally free of contamination, but care should be taken to protect them. The aquifers should be monitored to determine if usage is depleting the supply, and the long-term availability of ground water resources needs to be determined.

Much of the surface water contamination results from a lack of wastewater treatment plants and enforcement of treatment of effluents being discharged into the nation's waterways. The irrigation canals and ditches throughout the country are subject to improper disposal of waste, effectively serving as sewers, becoming more contaminated and brackish downstream. Additional wastewater treatment plants and proper disposal of sewerage could greatly decrease the amount of contamination entering the streams and canals.

The drainage and irrigation canals, which provide agricultural irrigation, have deteriorated due to lack of maintenance and as a result, have been unable to provide efficient crop irrigation and drainage. This system is, however, undergoing a major rehabilitation, which is being overseen by a new Drainage and Irrigation Board.

The sea defenses are in dire need of repair and long-term maintenance. Most of the population and its economic base are concentrated in the low-lying coastal areas, with a sea defense system designed to protect from invasion of the sea. Breaches due to lack of maintenance and repair have caused devastating damage. A coastal zone management program could be of great benefit to the country.

If adopted, recommendations in this report for technical training and for development of a national water resources management plan will have positive immediate and long-term results. Many of the other issues discussed in this report will require long-term commitments to effect change. Proper management of Guyana's water resources can provide a sustainable base for the country's economic growth.

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APPENDIX A

List of Officials Consulted

Many individuals in the public and private sectors were consulted and provided exceptional cooperation and support:

List of Officials Consulted

Name, Title	Agency/Firm	Address	Tel/Fax/Email
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Anthony Xavier, Minister of Public Works	Ministry of Public Works		
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APPENDIX B

Glossary

Glossary

air rotary	A well-drilling method that uses compressed air as a circulating medium.
alluvial	Pertaining to or composed of alluvium or deposited by a stream or running water.
andesite	A dense, fine-grained, dark colored to black, hard, extrusive igneous rock intermediate in composition between acidic and basic rocks. Andesite occurs principally as thick extensive lava flows.
aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.
artesian	Describes ground water that is under sufficient pressure to rise above the aquifer containing it. Flowing artesian wells are produced when the pressure is sufficient to force the water above the land surface.
basalt	A dense, fine-grained, dark-colored to black, hard, mafic (basic) extrusive igneous rock. Commonly consisting of small holes or vesicles and having columnar jointing. Basalt often occurs as thick massive lava flows covering vast areas.
bedding	Arranged or deposited in layers or beds.
bedding plane	In sedimentary or stratified rocks the division planes which separate individual strata.
biological contamination	The presence in water of significant quantities of disease-producing organisms.
brackish water	Water that contains total dissolved solids greater than 1,000 milligrams per liter but less than or equal to15,000 milligrams per liter.
breccia	Gravel-size or larger angular rock fragments in a finer grained material. Breccia is usually a highly unpredictable rock for construction purposes, and it is normally avoided by the military engineer.
Cenozoic	A period of geologic time from 65 million years ago to the present.
chemical contamination	Pollution from industrial or synthetic wastes.
chloride (Cl)	A negatively charged ion present in all natural waters. Excessive concentrations are undesirable for many uses of water. Chloride may be used as an indicator of domestic and industrial contamination.
confined aquifer	An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than the aquifer itself.
conglomerate	Gravel-size or larger, consolidated, rounded to semirounded rock fragments in a finer grained material.
consolidated	Where loosely aggregated, soft, or liquid earth materials have become firm and coherent rock.
contamination plume	A zone of polluted ground water down gradient from a point source of pollution.
Cretaceous	A period of geologic time 70 to 135 million years ago.

crop out	Rocks exposed on the surface.
cross-bedded	The arrangement of laminations of strata transverse or oblique to the main planes of stratification of the material concerned.
dewater	The process of either naturally or artificially removing water from a material, usually an aquifer.
diabase	An intrusive rock consisting essentially of labradorite and pyroxene.
dike	A tabular mass of igneous rock intruded in a crack or fissure.
discharge	The volume of water that passes a given point during a given period of time.
fault	A fracture or fracture zone of the Earth with displacement of one side relative to the other.
ferrous	Containing iron.
formation	A body of rock strata that consists dominantly of a certain lithologic type or combination of types.
fracture	A break in a rock with no significant displacement across the break.
fresh water	Water that contains 600 milligrams per liter or less of chlorides, 300 milligrams per liter or less of sulfates, and 1,000 milligrams per liter or less of total dissolved solids.
gabbro	A fine- to medium-grained, dark colored, hard, mafic (basic) intrusive, igneous rock. Gabbro occurs as lopoliths, dikes, and sills.
gaging station	A particular site on a stream, canal, lake, or reservoir where systematic observations of height or discharge are obtained.
gneiss	A medium- to coarse-grained, banded to weakly foliated, hard, metamorphic rock composed of alternating bands of light- and dark-colored minerals. Associated with mountains and rugged terrain.
gradient (slope)	The inclined surface of a hill, mountain, ridge, or any other part of the Earth's surface.
granite	A medium- to coarse-grained, light-colored, crystalline, hard, felsic (acidic) intrusive igneous rock with spaced joints. Granite often occurs as large dome-like masses forming prominent mountain peaks.
greenstone	An antiquated term that refers to altered basic igneous rocks which have green coloring due to the presence of chlorite, hornblende, and epidote.
head	Energy contained in a water mass, produced by elevation, pressure, or velocity.
high water	The flow occurring in a stream during the wettest part of the year.
igneous	A class of rock formed by the solidification of molten material. If the material is erupted onto the Earth's surface, the rock is called an extrusive or volcanic rock; if the material solidifies within the Earth, the rock is called an intrusive or plutonic rock.
impermeable	Bed or stratum of material through which water will not move.
infiltration	The flow or movement of water into the soil.

intermittent	Describes a stream or reach of a stream that flows only at certain times of the year, as when it receives water from springs or from some other source.
intrusive rock	Rock consolidated from magma beneath the Earth's surface that was squeezed into cracks or crevices or between layers of older rocks.
joint	A fracture in a rock formation along which there is no evidence of displacement. Represents various stresses that the rocks have experienced.
Jurassic	A period of geologic time in the middle Mesozoic era from 135 to 180 million years ago.
koker	A Dutch-Guyanan expression for canal gate.
laterite	A highly weathered, nutrient-poor, iron-rich, tropical soil with a high clay content that becomes very hard when dried and will not soften when rewetted.
Lower Proterozoic	In geologic time, the oldest era of Precambrian.
mangrove	A group of plants that grows in a tropical or subtropical marine swamp. A marine swamp dominated by a community of these plants.
Mesozoic	A period of geologic time from 65 to 240 million years ago.
metamorphic	A rock (e.g., schist, gneiss, etc.) that was formed by solid state transformation from a preexisting rock, through heat, pressure, the effect of superheated fluids, or any combination of these forces.
Middle Proterozoic	In geologic time, the middle era of the Precambrian.
mineralization	The process by which inorganic substances are added to a body.
mud rotary	A well-drilling method that uses mud as a circulating medium.
overburden	Material of any nature, consolidated or unconsolidated, that lies directly above the deposit of interest.
percussion	A drilling method that involves crushing rock by impact from the drill bit driven by drillingdown-hole, pneumatic-percussion hammer rigs.
perennial	Pertaining to water that is available throughout the year.
permeability (rock)	The property or capacity of a porous rock for transmitting a fluid. Permeability is a measure of the relative ease of fluid flow under unequal pressure.
Permian	A period of geologic time in the Paleozoic era from 225 to 270 million years ago.
pH	Hydrogen-ion concentration: a measure of the acidity or basicity of a solution.
phyllite	A fine-grained, foliated, soft metamorphic rock that is intermediate in composition and fabric between slate and schist. Phyllite is commonly thin layered and associated with mountains and rugged terrain.
piezometric	The level to which water in an aquifer will rise under its full head.
Pliocene	The period of geologic time in the Tertiary Period, between 2 and 5 million years ago.

pluton	Any deep, intrusive, igneous body of any size whose exact form has not been determined.
potable water	Water that does not contain objectional pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.
Precambrian	All geologic time older than approximately 570 million years ago; the age of the earth's oldest rocks.
quartz	The mineral silica dioxide (SiO_2).
quartzite	An extremely hard, fine- to coarse-grained crystalline, mostly white, massive metamorphic rock which formed by recrystallization of sandstone or chert.
Quaternary	A period of geologic time from the present to about 2 million years ago.
Recent	A period of geologic time extending from the present to about 1 million years ago; also referred to as the Holocene; falls within the Quaternary Period.
recharge	The process by which water infiltrates into the zone of saturation.
runoff	That portion of the precipitation in a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, and seepage.
saline water	Water containing greater than 15,000 milligrams per liter of total dissolved solids. Saline water is undrinkable without treatment.
saltwater intrusion	Displacement of fresh surface or ground water by the advance of salt water due to its greater density. Saltwater intrusion usually occurs in coastal and estuarine areas where it contaminates fresh water wells.
sandstone	A medium- to coarse-grained, soft to moderately hard sedimentary rock composed primarily of quartz grains held together by compaction in the presence of clay or through cementation by silica, iron oxides, carbonates, or clay. Sandstone is mostly well stratified, thin to thick bedded, and sometimes massive.
saturation	The extent to which the available pore space within a material has been filled by water.
schist	A fine- to coarse-grained crystalline, strongly foliated, metamorphic rock composed of discontinuous arrangement of thin parallel layers of large platy minerals. Outcrops commonly show foliation structures in tilted or folded attitudes. Schist is associated with mountainous and rugged terrain characterized by rounded crests.
sedimentary (rock)	A layered rock, formed through the accumulation and solidification of sediments, which may originally be made up of minerals, rock debris, or animals or vegetable matter.
shale	A soft to moderately hard, compacted to somewhat indurated, massive to laminated sedimentary rock composed of very fine-grained quartz particles. Shale often weathers or breaks into very thin platy pieces or flakes.
siltstone	A fine-grained, moderately hard, sedimentary rock that is thin bedded to massive. Siltstone is distinguished from shale because it has a slightly larger grain size.
sorted	A material in which the individual particles have been categorized by either size, shape, or specific gravity and deposited.

suspended solids	Insoluble solids that either float on the surface of or are suspended in water, wastewater, or other liquids.
total dissolved solids (TDS)	The sum of all dissolved solids in water or waste water.
Triassic	A period of geologic time between 185 and 240 million years ago; the earliest/oldest division of the Mesozoic Era.
tuff	A fine-grained, mostly light-colored, soft, porous rock composed of small volcanic rock fragments and ash moderately compacted forming a texture more characteristic of sedimentary rocks.
unconsolidated	Loose, soft, or liquid earth materials that are not firm or compacted.
volcanic ash	Fine pyroclastic matter composed of particles that are less than 2 millimeters in diameter.
water point	Intake site located next to a water source from which water is withdrawn.
water table	The depth or level below which the ground is saturated with water.
watershed	The area contained within a drainage divide above a specified point on a stream.
yield or well yield	The volume in liters per minute of water produced from a well.

APPENDIX C

Surface Water and Ground Water Resources

Tables and Figures

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Table C-1. Surface Water Resources					
Map Unit (See Fig. C-1)	**Sources**	**Quantity[1]**	**Quality[2]**	**Accessibility**	**Remarks**
1 Fresh water perennially available	Major perennial rivers and streams draining from the lowland valleys and mountainous areas throughout the country. Selected major rivers: Berbice River (0617N05732W)[3], Canje River (0616N05732W), Cuyuni River (0623N05841W), Courantyne River (0557N05706W), Demerara River (0623N05841W), Essequibo River (0659N05823W), Illiwa River (0619N06016W), Mazaruni River (0625N05838W), New River (0323N05736W), Potaro River (0522N05854W), Rupununi River (0403N05835W), and Tapakuma River (0713N05842W).	Enormous quantities are available year-round from rivers, streams, and lakes throughout the country. High flow occurs during two periods, the longest from April to August and the shortest from November to January. Streamflows are highly variable because of significant variation in rainfall between seasons and from year to year. Selected stream gaging stations with minimum discharges between 1965 and 1996 are given below. (Numbers in bold correspond with placement numbers shown on Figure C-1.) **1** Mazaruni River at Apaikwa Falls (0621N06022W), 1,434,120 L/min; **2** Cuyuni River at the mouth of Akarabisi River (0655N06022W), 1,733,184 L/min; **4** Cuyuni River at Kamaria Falls (0625N05849W), 1,444,320 L/min; **8** Tapakuma River at Dawa (0712N05836W), 872,340 L/min; **12** Mazaruni River at Kamarang (0552N06037W), 2,225,952 L/min; **13** Mazaruni River at Illadabu Mountain (0555N06038W), 3,262,464 L/min; **14** Mazaruni River at Hillfoot (0551N05933W), 1,869,120 L/min; **15** Potaro River at Kaieteur Falls (0509N05929W), 1,237,020 L/min; **17** Potaro River at Tumatumari (0522N05900W), 2,361,888 L/min; **21** Essequibo River at Plantain Island (0551N05834W), 1,247,220 L/min;	Water is generally fresh with TDS ranging from 9.8 to 12.4 mg/L. Water is typically soft. However, biological and chemical contamination is common, especially near populated areas. In most areas, waste water is untreated. Agricultural and industrial wastes have possibly contaminated most sources. Turbidity is generally common during periods of high water. Salt water intrusion extends beyond the best agricultural areas in the Berbice River. Water cannot be used directly for irrigation in the area. Chemical water pollution is possible from mining operations. Possible cyanide contamination exists along the Omai River and along the Essequibo River. Selected sites with water quality data are given for different times of the year during 1995 and 1996. (Numbers in bold correspond with placement numbers shown on Figure C-1.) **1** Mazaruni River at Apaikwa Falls (0621N06022W): Suspended solids1 mg/L; dissolved oxygen 13.8 mg/L; $CaCO_3$ as Mg 0.22 mg/L; Mg 0.06 mg/L; $CaCO_3$ as Ca 0.58 mg/L; Ca 0.22 mg/L; NO_2 0.4 mg/L; Fe 0.16 mg/L. **12** Mazaruni River at Kamarang (0553N06036W): Ca 2.3 to 25.5 mg/L. **14** Mazaruni River at Hillfoot (0551N05933W): Suspended solids 15 to 21 mg/L. **18** Essequibo River above Omai (0526N05845W): TDS 9.5 to 12.46 mg/L; suspended solids 19 to 20 mg/L;pH 7.44 to 7.58; dissolved oxygen 6.4 to 12.4 mg/L;	Access and development of water points are principally influenced by topography, ground cover, and lack of roads. In mountainous areas, the rugged terrain, steep gradients, deep gorges, and waterfalls restrict access. Dense vegetation and lack of roads in the interior also make access to water points difficult. During the wet seasons, existing roads become virtually impassable. In the coastal lowlands, access and development of water points are generally easier than in the interior due to a better developed transportation system and gentler topography.	Protection of equipment against flooding and debris from intense tropical storms is recommended. After heavy rains, the rivers rise rapidly with swift currents and contain floating debris that can damage or destroy water points. Seasonal maintenance of intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.

Table C-1. Surface Water Resources (continued)					
Map Unit (See Fig. C-1)	**Sources**	**Quantity[1]**	**Quality[2]**	**Accessibility**	**Remarks**
1 (continued) Fresh water perennially available		**24** Essequibo River at Kuratoka Falls (0430N05830W), 5,879,232 L/min; **25** Demerara River at Saka (0534N05822W), 749,347 L/min; **28** Canje River near Three Sisters (0535N05735W), 567,533 L/min; **29** Canje River at Friendship (0549N05728W), 870,480 L/min; **32** Essequibo River at King William Falls (0320N05814W), 1,733,160 L/min. Selected stream gaging stations with average discharges are listed below. **1** Mazaruni River at Apaikwa Falls (0621N06022W), 47,812,000 L/min; **4** Cuyuni River at Kamaria Falls (06256N05849W), 66,960,000 L/min; **8** Tapakuma River at Dawa (0712N05836W), 939,000 L/min; **14** Mazaruni River at Hillfoot (0551N05933W), 81,480,000 L/min; **15** Potaro River at Kaieteur Falls (0509N05929W), 14,791,000 L/min; **17** Potaro River at Tumatumari (0522N05901W), 33,774,000 L/min; **21** Essequibo River at Plantain Island (0551N05834W), 131,820,000 L/min; **24** Essequibo River at Kuratoka Falls (0430N05830W), 76,020,000 L/min; **25** Demerara River at Saka (0534N05822W), 6,900,000 L/min; **28** Canje River at Three Sisters (0535N05735W), 1,158,000 L/min;	$CaCO_3$ as Mg 1.02 to 2.09 mg/L; Mg 0.24 to 0.5 mg/L; $CaCO_3$ as Ca 0.9 to 1.51 mg/L; Ca 0.35 to 0.7 mg/L; NO_2 0.004 to 1.2 mg/L; Fe 0.67 to 1.07 mg/L; NO_3 0.8 mg/L. **19** Essequibo River below Omai (0526N05845W): TDS 8.4 mg/L; suspended solids 8 mg/L; pH 7; dissolved oxygen 7.2 mg/L; $CaCO_3$ as Mg 1.6 mg/L; Mg 0.4 mg/L; $CaCO_3$ as Ca 1.07 mg/L; Ca 0.42 mg/L; NO_2 0.06 mg/L; Fe 0.65 mg/L; CN 0.002 mg/L. **21** Essequibo River at Plantation Island (0551N05834W): TDS 10.08 to 12.39 mg/L; suspended solids 2 to 14 mg/L; pH 6.15 to 7.05; dissolved oxygen 6.1 to 7 mg/L; $CaCO_3$ as Mg 1.23 to 1.77 mg/L; Mg 0.3 to 1.55 mg/L; $CaCO_3$ as Ca 0.76 to 1.43 mg/L; Ca 0.29 to 0.92 mg/L; NO_2 0.009 to 0.5 mg/L; Fe 0.41 to 0.96 mg/L; CN 0.001 mg/L; NO_3 0.8 mg/L. **22** Essequibo River at Rockstone (0559N05833W): TDS 10.99 to 11.9 mg/L; suspended solids 9 to 46 mg/L; pH 6.58 to 8.72; dissolved oxygen 5.8 to 11.4 mg/L; $CaCO_3$ as Mg 1.06 to 1.9 mg/L; Mg 0.33 to 0.44 mg/L; $CaCO_3$ as Ca 0.8 to 4.15 mg/L; Ca 0.4 to 1.67 mg/L; NO_2 0.02 to 0.8 mg/L; Fe 0.45 to 1 mg/L; CN 0.002 to 0.007 mg/L; NO_3 0.09 mg/L. **28** Canje River near Three Sisters (0535N05735W): TDS 9.8 mg/L; pH 4.47; dissolved oxygen 5.9 mg/L; $CaCO_3$ as Mg 0.97 mg/L;		

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
1 (continued) Fresh water perennially available		**29** Canje River at Friendship (0549N05728W), 918,000 L/min; **32** Essequibo River at King William Falls (0320N05814W), 40,904,000 L/min.	Mg 0.24 mg/L; $CaCO_3$ as Ca 1.87 mg/L; Ca 1.2 mg/L; NO_2 0.3 mg/L.		
2 Fresh water perennially available	Perennial rivers and streams generally draining the interior plains (0600N05900W) and western highlands (0500N05930W). Selected major rivers are as follows: Arapaiko River (0716N05843W); Barima River (0835N06025W); Upper Berbice River (0549N05740W); Upper Canje River (0515N05737W); Cuyuni River (0623N05841W); Upper Demerara River (0518N05832W); Kairuni River (0624N06010W); Loo River (0615N05817W); Pomeroon River (0737N05845W); Siparuni River (0450N05850W); Supenaam River (0659N05831W); and Truli River (0631N05817W).	Enormous quantities are available from April through August and November through January from rivers and streams. Large to very large quantities are available the rest of the year. High flow generally occurs during two periods, the longest from April to August and the shortest from November to January. Streamflows are highly variable because of significant variation in rainfall between seasons and from year to year. Selected stream gaging stations with minimum discharges between 1965 and 1996 are given below. (Numbers in bold correspond with placement numbers shown on Figure C-1.) **3** Barima River at Mekorusa Falls (0738N06030W), 33,960 L/min; **5** Supenaam River at Cooper's Landing (0653N05843W), 176,717 L/min; **6** Pomeroon River at Truli River (0706N05842W), 54,360 L/min; **7** Pomeroon River at Arapaiko River (0707N05842W), 37,382 L/min; **9** Kairuni Creek at Kairuni Bridge (0610N05814W), 30,600 L/min; **11** Loo River at Soesdyke (0614N05825W), 59,460 L/min; **16** Siparuni River at Pakutau Falls (0445N05901W), 81,562 L/min;	Water is generally fresh with TDS ranging from 9.52 to 53.9 mg/L. Water is typically soft. However, biological and chemical contamination is common, especially near populated areas. In most areas, waste water is untreated. Agricultural and industrial wastes have possibly contaminated most sources. Turbidity is generally common during periods of high water. Selected sites with water quality data are given for different times of the year during 1995 and 1996. (Numbers in bold correspond with placement numbers shown on Figure C-1.) **10** Kairuni River at Soesdyke/ Linden Highway Bridge (0632N05815W): TDS 53.9 mg/L; pH 4.43; dissolved oxygen 6.4 mg/L; $CaCO_3$ as Mg 0.87 mg/L; Mg 0.21 mg/L; $CaCO_3$ as Ca 1.63 mg/L; Ca 1.14 mg/L; Fe 0.21 mg/L; CN 0.001 mg/L. **11** Loo River (0614N05825W): Suspended solids 4 mg/L; dissolved oxygen 9.1 mg/L; $CaCO_3$ as Mg 1.17 mg/L; Mg 0.28 mg/L; $CaCO_3$ as Ca 0.54 mg/L; Ca 0.33 mg/L; NO2 1.7 mg/L; Fe 0.49 mg/L. **20** Omai River (0526N05845W): TDS 9.52 to 16.24 mg/L; suspended solids 14 to 61 mg/L; pH 4.2 to 6.45; dissolved oxygen 5.5 to 6.9 mg/L; $CaCO_3$ as Mg 1.31 to 2.35 mg/L; Mg 0.33 to 0.57 mg/L;	Access and development of water points are principally influenced by topography, ground cover, and the transportation network (lack of roads). In mountainous areas, the rugged terrain, steep gradients, deep gorges, and waterfalls restrict access. Dense vegetation and lack of roads in the interior also make access to water points difficult. During the wet season, existing roads become virtually impassable. In the coastal lowlands, access and development of water points are generally easier than in the interior due to a better developed transportation system and gentler topography.	Protection of equipment against flooding and debris during the wet season is recommended. After heavy rains, the rivers rise rapidly with swift currents and contain floating debris that can damage or destroy water points. Seasonal maintenance of intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.

Table C-1. Surface Water Resources (continued)					
Map Unit (See Fig. C-1)	**Sources**	**Quantity[1]**	**Quality[2]**	**Accessibility**	**Remarks**
2 (continued) Fresh water perennially available		**23** Demerara River at Great Falls (0518N05832W), 300,758 L/min; **26** Berbice River at Itabu Falls (0452N05013W), 40,800 L/min; **27** Canje River at Reynold's Bridge (0515N05737W), 86,659 L/min. Selected stream gaging stations with average discharges are listed below. (Numbers in bold correspond with placement numbers shown on Figure C-1.) **3** Barima River at Mekorusa Falls (0738N06030W), 2,964,000 L/min; **6** Pomeroon River at Truli River (0706N05842W), 219,000 L/min; **7** Pomeroon River at Arapaiko River (0707N05842W), 450,000 L/min; **9** Kairuni Creek at Kairuni Bridge (0610N05814W), 63,990 L/min; **11** Loo River at Soesdyke (0614N05825W), 105,800 L/min; **23** Demerara River at Great Falls (0518N05832W), 4,313,000 L/min; **26** Berbice River at Itabu Falls (0452N05013W), 2,838,000 L/min.	$CaCO_3$ as Ca 0.64 to 1.26 mg/L; Ca 0.25 to 0.94 mg/L; NO_2 0.009 to 1.2 mg/L; Fe 0.71 to 0.8 mg/L; CN 0.001 to 0.091 mg/L; NO_3 0.7 mg/L. **23** Demerara River at Great Falls (0518N05832W): TDS 11.9 mg/L; suspended solids 20 mg/L; dissolved oxygen 6.3 mg/L; $CaCO_3$ as Mg 1.55 mg/L; Mg 0.39 mg/L; $CaCO_3$ as Ca 1.17 mg/L; Ca 0.46 mg/L; Fe 0.59 mg/L; CN 0.012 mg/L; NO_2 1 mg/L. **27** Canje River at Reynold's Bridge (0515N05737W): TDS 20.3 mg/L; pH 5.97; dissolved oxygen 6.1 mg/L; $CaCO_3$ as Mg 1.18 mg/L; Mg 0.3 mg/L; $CaCO_3$ as Ca 0.48 mg/L; Ca 0.18 mg/L; NO_2 0.29 mg/L; Fe 0.11 mg/L. **30** Ikuruwa River (0540N05726W): TDS 25.9 mg/L; pH 3.50; dissolved oxygen 6.3 mg/L; $CaCO_3$ as Mg 1.89 mg/L; Mg 0.46 mg/L; $CaCO_3$ as Ca 3.92 mg/L; Ca 0.98 mg/L; NO_2 0.02 mg/L; Fe 0.66 mg/L.		
3 Fresh water seasonally plentiful	Perennial and intermittent streams, tributaries, canals, and ditches in the coastal lowlands (0645N05815W), interior plains, and a small area in the western highlands. Two major rivers are	Large quantities are available from April through August and November through January from perennial and intermittent streams. Small to moderate quantities are available from perennial streams the rest of the year. Intermittent streams may go dry from February to September to October. High flow generally occurs during two periods, the longest from April to August and the shortest from November to January.	Water is generally fresh and soft. However, biological and chemical contamination is common, especially near populated areas. In most areas, waste water is untreated. Agricultural and industrial wastes may have contaminated most sources. Turbidity is generally common during periods of high water. Biological contamination is common near villages.	Access and development of water points are principally influenced by topography, ground cover, and the lack of roads. In the coastal lowlands, access and development of water points are generally easier than in the interior due to a better developed	Protection of equipment against flooding and debris from intense tropical storms is recommended. After heavy rains, the rivers rise rapidly with swift currents and contain floating debris that can damage or destroy water points. Seasonal maintenance of

Table C-1. Surface Water Resources (continued)

Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
3 (continued) Fresh water seasonally plentiful	the Mahaicony River (0634N05748W) and the Wiruni Creek (0610N05743W).	Streamflows are highly variable because of significant variation in rainfall between seasons and from year to year.		transportation system and gentle topography.	intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.
4 Fresh water seasonally plentiful	Perennial and intermittent streams and tributaries in the central and southern uplands (0230N05815W). Selected major rivers are as follows: Kuyuwini River (0216N05816W), Kassikaityu River (0150N05833W), Oronoque River (0245N05725W), and Takutu River (0301N06029W).	Large quantities are available from April through August. Meager to moderate quantities are available from perennial streams the rest of the year. Intermittent streams may go dry from February to March and from September to October. High-flow period generally occurs from April to August. Streamflows are highly variable because of significant variation in rainfall between seasons and from year to year. The stream gaging station given below is shown in Figure C-1. **31** Takutu River at St. Ignatius (032105948W). This stream gaging station has a minimum discharge of 1,376 L/min from 1972 to 1973.	Water is generally fresh. Biological and chemical contamination may be present near villages. In most areas, waste water is untreated. Turbidity is generally common during periods of high water.	Access and development of water points are principally influenced by topography, ground cover, and the transportation network (lack of roads). In the central and southern uplands, the terrain, steep gradients, deep gorges, and waterfalls restrict access. Dense vegetation and lack of roads in the interior also make access to water sources difficult.	Protection of equipment against flooding during the wet season is recommended. After heavy rains, the rapid rise of the rivers can damage or destroy water points. Seasonal maintenance of intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.
5 Fresh water seasonally plentiful	Perennial and intermittent streams and tributaries in the southwest savannah (0345N05935W) and small tributaries of the Amazon River.	Moderate to large quantities are available from April through August. Meager to small quantities are available throughout the rest of the year. Intermittent streams generally go dry especially from February to March and from September to October. High-flow period generally occurs from April to August. Streamflows are highly variable because of significant variation in rainfall between seasons and from year to year. During long dry periods, many perennial and intermittent streams may cease to flow. The Rupununi River has occasionally stopped flowing.	Water is generally fresh. Biological and chemical contamination may be present near villages. In most areas, waste water is untreated. Turbidity is generally common during periods of high water.	Access and development of water points is primarily difficult due to the lack of a developed transportation system. Vegetation is open grasslands with sparse trees. Terrain is generally flat and subject to flooding during the wet season.	Protection of equipment against flooding and debris from intense tropical storms is recommended. After heavy rains, the rapid rise of the rivers can damage or destroy water points. Seasonal maintenance of intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.
6 Fresh water scarce or lacking	Mouths of rivers and streams with tidal influences, coastal marshes, mangrove	Large to enormous quantities of brackish to saline water are available year-round along the coast	Water is generally brackish. The concentration of salinity varies with the amount of flow in the sections of the rivers and streams	In the coastal lowlands, access and development of water points are generally easier than	Protection of equipment against flooding and debris from intense tropical storms is

Table C-1. Surface Water Resources (continued)					
Map Unit (See Fig. C-1)	Sources	Quantity[1]	Quality[2]	Accessibility	Remarks
6 (continued) Fresh water scarce or lacking	swamps, and tidal lowlands.		influenced by tides. During low-flow periods, brackish water is found farther inland than during high-flow periods. Biological and chemical contamination is also common, especially near populated areas. In most areas, waste water is untreated. Agricultural and industrial wastes probably have contaminated most sources.	elsewhere due to a better developed transportation system and gentler topography. Access and establishment of water points are difficult in mangrove swamps and on soft, wet terrain.	recommended. After heavy rains, the rivers rise rapidly with swift currents containing floating debris that can damage or destroy water points. Seasonal maintenance of intake equipment along channels carrying high sediment loads is recommended to counter rapid silting.

[1]Quantitative Terms:

Enormous	= >400,000 L/min (100,000 gal/min)
Very large	= >40,000 to 400,000 L/min (10,000 to 100,000 gal/min)
Large	= >4,000 to 40,000 L/min (1,000 to 10,000 gal/min)
Moderate	= >400 to 4,000 L/min (100 to 1,000 gal/min)
Small	= >40 to 400 L/min (10 to 100 gal/min)
Very small	= >4 to 40 L/min (1 to 10 gal/min)
Meager	= $\leq$4 L/min (1 gal/min)

[2]Qualitative Terms:

Fresh water	= maximum TDS $\leq$1,000 mg/L; maximum chlorides $\leq$600 mg/L; and maximum sulfates $\leq$300 mg/L
Brackish water	= maximum TDS >1,000 mg/L but $\leq$15,000 mg/L
Saline water	= TDS >15,000 mg/L

Hardness Terms:

Soft	= 0 to 60 mg/L $CaCO_3$
Moderately hard	= 61 to 120 mg/L $CaCO_3$
Hard	= 121 to 180 mg/L $CaCO_3$
Very hard	= >180 mg/L $CaCO_3$

[3]Geographic coordinates list latitude first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or Western (W) Hemisphere. For example:

Berbice River. . . . . (0617N05732W)

Geographic coordinates for the Berbice River that are given as 0617N05732W equal 6°17'N 57°32' W and can be written as a latitude of 6 degrees and 17 minutes north and a longitude of 57 degrees and 32 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Coordinates are approximate.

Note:

Ca	= calcium
$CaCO_3$	= calcium carbonate
CN	= carbon-nitrogen
Fe	= iron
gal/min	= gallons per minute
L/min	= liters per minute
Mg	= magnesium
mg/L	= milligrams per liter
NO_2	= nitrogen-oxygen
NO_{3-}	= nitrate
pH	= potential of hydrogen
TDS	= total dissolved solids

Conversion Chart:

To Convert	Multiply By	To Obtain
liters per minute	0.264	gallons per minute
liters per minute	15.852	gallons per hour
liters per minute	380.517	gallons per day

Table C-2. Ground Water Resources

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
1 Fresh water generally plentiful	Extensive confined artesian aquifers consisting primarily of Cenozoic marine sands and gravels form three distinct water-bearing zones. This group of three aquifers is often referred to as the coastal aquifer system. The Upper Sands aquifer is the shallowest unit, the A Sand is the middle unit, and the B Sand is the deepest aquifer of this system. These aquifers are separated by confining layers of marine clay. The A Sand aquifer supplies water along the coastal plain. Because of the high cost of well completion, only recently have wells been drilled into the B Sand aquifer for water extraction. The coastal aquifer system occupies a land surface area of nearly 20,000 km^2 extending for 250 km along the Atlantic coast. From the Courantyne River (0323N05736W)[3] in the east to the Amakura River (0832N06028W) in the west and as far south or inland as Vigilantie (0551N05742W). This system is in the following administrative divisions: Barima-Waini (0740N05945E), Pomeroon-Supenaam (0705N05850W), Essequibo Islands-West Demerara (0640N05830W), Demerara-Mahaica (0630N05805W), Mahaica-Berbice (0615N05750W), East Berbice-Corentyne (0400N05810W), and Upper Demerara-Berbice (0530N05820W). Berbice-Corentyne (0400N05810W), and Upper Demerara-Berbice (0530N05820W).	Large quantities of water are available year-round from the Upper Sands, the A Sand, and the B Sand aquifers. These are Guyana's most productive aquifers. The highest degree of ground water development of these aquifers is in the vicinity of Georgetown (0648N05810W).	Fresh throughout the region for the A and B Sand aquifers. The Upper Sands aquifer is brackish with TDS of >1,200 mg/L. During periods of low flow, saltwater intrusion is probable along the Essequibo (0702N05827W) and Berbice (0617N05732W) Rivers. Otherwise, the aquifers are not affected by saltwater intrusion along the coast, possibly due to the confining effects of the clays, direction of ground water flow, and the aquifers' heads. The Upper Sands aquifer has a high iron content of >5 mg/L. The A Sand aquifer has elevated carbon dioxide and iron content that can corrode ferrous- and cement-based materials. The B Sand aquifer has temperatures of 40.5^o C (105^o F) and contains traces of H_2S.	Depth to water ranges from 30 to 60 m below the surface, and thickness ranges from 15 to 120 m for the Upper Sands aquifer. The A Sand aquifer is at depths ranging from 150 to 215 m and is 12 to 27 m thick. The B Sand aquifer is at depths from 350 to 800 m and ranges in thickness from 15 to 60 m. Water will rise under pressure from the confined A and B Sand aquifers to 14 m below ground surface. Access is easy along the coastal plain due to the number of all-weather roads. Mud rotary drilling with steel bits is recommended to drill wells.	The ground water is primarily used for domestic and industrial water supply. Numerous wells exist in the coastal aquifer system. The Guyana Water Authority must authorize all drilling. Recharge of this system occurs through infiltration of the White Sands Formation, which crops out 35 km south of Georgetown. Along the coast, overpumping of wells may result in saltwater intrusion. Large quantities (4,000 to 40,000 L/min) of water will support military or humanitarian civic assistance (HCA) water wells. Ground water exploration is recommended in this map unit.
2 Fresh water generally plentiful	The White Sands Formation, which crops out to the immediate south of the coastal alluvial aquifers, is an aquifer that is composed of Pliocene to Recent angular to sub-angular quartz sand. The town of Linden (0600N05818W) is near the center of this aquifer. Lateritic clay, several meters thick, is the typical overburden for much of this unit. The White Sands	Moderate to large quantities of water are available year-round from the sand and sandstone deposits of the White Sands aquifer. Moderate quantities of water are available from the Takutu aquifer.	Water withdrawn from the White Sands aquifer is considered to be fresh. TDS levels increase toward the coast as residence time and mineralization of the water occur. Water from the Takutu aquifer is considered to be fresh.	Depths to static water level in the White Sands aquifer are generally <30 m, and the thickness varies from 15 to 90 m. Depth to water in the Takutu aquifer series is up to 75 m with a formation thickness of	Only a limited number of wells with associated data are known to exist in these formations. Recharge occurs naturally from precipitation throughout the wet season. The White Sands Formation is probably the recharge site for the coastal A and B Sand aquifers. Moderate yields (400 to

Table C-2. Ground Water Resources (continued)					
Map Unit (See Fig. C-2)	**Aquifer Characteristics**	**Quantity[1]**	**Quality[2]**	**Aspects of Ground Water Development**	**Remarks**
2 (continued) Fresh water generally plentiful	aquifer is in the following administrative divisions: Pomeroon-Supenaam (0705N05850W), Essequibo Islands-West Demerara (0640N05830W), Demerara-Mahaica (0630N05805W), Mahaica-Berbice (0615N05750W), East Berbice-Corentyne (0400N05810W), Cuyuni-Mazaruni (0600N06000W), and Upper Demerara-Berbice (0530N05820W). The Takutu Sandstone aquifer is in southern Guyana in the Rupununi Savannahs (0300N05930W). The town of Lethem (0323N05948W) is within the Takutu aquifer. The Takutu is composed of Permian to Triassic cross-bedded sandstones interbedded with lesser amounts of blocky siltstones and shales which are >600 m thick. This unit underlies an area of about 5,200 km^2 within the Upper Takutu-Upper Essequibo (0230N05900W) administrative division. Overlying the Takutu is the Nappi Formation, a thin layer of lateritic deposits.			>600 m. Access is difficult due to lack of all-weather roads. Mud rotary drilling with steel bits is recommended to drill wells in both aquifers.	4,000 L/min) and greater will support 3,000- and 15,000-gal/d reverse osmosis water purification units (ROWPUs) and most irrigation and municipal water supply wells.
3 Fresh water locally plentiful	Extensive unconfined to confined aquifers in consolidated to unconsolidated volcanic pyroclastic deposits of the Roraima Group. These deposits were probably formed during the Middle Proterozoic Era and are composed of volcanic ash, tuff, breccia, sand, and conglomerates. Scattered with these pyroclastic deposits are intrusive diabase dikes with associated contact metamorphic rocks. This aquifer is throughout the mountains of the southwestern and central parts of the country in the following administrative divisions: Cuyuni-Mazaruni (0600N06000W), Potaro-Siparuni (0500N05930W), and Upper Demerara-Berbice (0530N05820W).	Small to large quantities of water are available from the pyroclastic deposits. Springs in this region produce small amounts of water. The most productive zones in this aquifer are along fractures and unconformities between deposits.	Fresh from all known sources.	Depth to water ranges from 10 to 300 m, depending upon the depth of overburden and the extent of fracturing. Mud rotary drilling with steel bits would be sufficient for most of the aquifer materials. Access is very difficult in most locations due to lack of all-weather roads, thick vegetation, and steep slopes.	Recharge is negligible due to the rapid runoff on the steep slopes. Small yields (40 to 400 L/min) will support tactical wells, 600-gal/d ROWPUs, and most HCA submersible pump wells. Moderate yields (400 to 4,000 L/min) and greater will support 3,000- and 15,000-gal/d ROWPUs and most irrigation and municipal water supply wells.

Table C-2. Ground Water Resources (continued)					
Map Unit (See Fig. C-2)	**Aquifer Characteristics**	**Quantity[1]**	**Quality[2]**	**Aspects of Ground Water Development**	**Remarks**
4 Fresh water locally plentiful	Extensive igneous deposits in the northwestern to the southeastern part of Guyana. The aquifer is typically composed of granites, volcanic sub-granites, cherty mudstones, gravels, and scattered sand deposits. The granitic deposits in the northwest belong to the Younger Granites Group of the Middle Proterozoic. The southern granites belong to the Kuyuwini Group, which underlies about 3,300 km^2 in southern Guyana. These aquifers are in the following administrative divisions: Barima-Waini (0740N05945E), Pomeroon-Supenaam (0705N05850W), East Berbice-Corentyne (0400N05810W), Cuyuni-Mazaruni (0600N06000W), Potaro-Siparuni (0500N05930W), Upper Takutu-Upper Essequibo (0230N05900W), and Upper Demerara-Berbice (0530N05820W).	Small to moderate amounts of water are available from the igneous intrusive, plutonic rocks. Water is generally only available within the breccia of fracture zones.	Fresh from all known sources. TDS values increase during the dry season, especially in the southern areas of the country where resident times may be longer.	Depth to water ranges from 3 to 150 m and varies with the season and percent of slope of the site. Granites exceed >100 m in thickness in most locations. Air rotary or percussion drilling with carbide bits is recommended in the granitic rock. Drilling is slow and difficult in these rock types. Access is very difficult in most locations due to steep terrain and lack of all-weather roads.	In the mountainous areas, high runoff rates on steep slopes and the impermeable nature of the rock result in negligible recharge. Ground water exploration in this region would be costly and is not recommended. Small yields (40 to 400 L/min) will support tactical wells, 600-gal/h ROWPUs, and most HCA submersible water pump wells. Moderate yields (400 to 4,000 L/min) will support 3,000- and 15,000-gal/d ROWPUs and most irrigation and municipal water supply wells.
5 Fresh water scarce or lacking	Extensive metamorphic deposits trending from the northwestern to the southeastern part of Guyana. Aquifers are typically composed of phyllites, schists, gneisses, and quartzites, referred to as 'greenstones' which indicate the degree of metamorphism that has occurred. The metamorphic deposits in the northwest belong to the Barama-Mazaruni Group of the Lower Proterozoic. The southern metamorphics belong to the Kwitaro (metasedimentary deposits) and the Kanuku Groups. These aquifers are in the following administrative divisions: Barima-Waini (0740N05945E), Pomeroon-Supenaam (0705N05850W), East Berbice-Corentyne (0400N05810W), Cuyuni-Mazaruni (0600N06000W), Potaro-Siparuni (0500N05930W), Upper Takutu-Upper Essequibo (0230N05900W), and Upper Demerara-Berbice (0530N05820W).	Meager to moderate amounts of ground water are available from fractures, along bedding planes, and in the limited pore spaces of the softer, poorly consolidated metamorphic units. The most productive areas within the units are the fracture zones.	Primarily fresh throughout the aquifer. The northern deposits may locally contain chloride, which elevates TDS levels.	Depth to water varies from 10 to 300 m, depending on seasonal variations, rock type, and percent slope. Air rotary or percussion drilling with carbide bits is recommended in these metamorphic deposits. Access is very difficult in most locations due to steep terrain and lack of all-weather roads.	Drilling in this aquifer has been primarily limited to mineral exploration with only limited available data on ground water. Recharge occurs throughout the wet season, but is negligible on the steeper slopes. Ground water development in this region is very costly. Meager yields will not support military and HCA wells. Very small yields (4 to 40 L/min) will support most hand pump wells. Small yields (40 to 400 L/min) will support tactical wells, 600-gal/h ROWPUs, and most HCA submersible pump wells. Moderate yields (400 to 4,000 L/min) will support 3,000 and 15,000 gal/d ROWPU'S and most irrigation and municipal water supply wells.

Table C-2. Ground Water Resources (continued)

Map Unit (See Fig. C-2)	Aquifer Characteristics	Quantity[1]	Quality[2]	Aspects of Ground Water Development	Remarks
6 Fresh water scarce or lacking	Scattered areas of igneous dikes and sills, volcanic welded tuffs, and andesitic lava flows are throughout the central and southern parts of the country. The intrusive igneous deposits are primarily composed of gabbro of the Avanavero Suite of the Middle Proterozoic. The welded tuffs and the andesite deposits represent the Apoteri Group of the Takutu Graben, which is Lower Cretaceous to Upper Jurassic in age. These deposits are in the following administrative divisions: East Berbice-Corentyne (0400N05810W), Cuyuni-Mazaruni (0600N06000W), Potaro-Siparuni (0500N05930W), Upper Takutu-Upper Essequibo (0230N05900W), and Upper Demerara-Berbice (0530N05820W).	Meager to very small amounts of water are available almost exclusively from fracture zones.	Fresh from sources throughout the aquifer.	Depth to water is highly variable throughout the mountainous terrain. Depth will vary from 3 to 150 m and will fluctuate with the season, which is more distinct in the south. Air rotary or percussion drilling with carbide bits is recommended in the igneous deposits. Access is very difficult in most locations due to steep terrain and lack of all-weather roads.	Recharge occurs throughout the wet season, but is negligible on the steeper slopes. Meager yields will not support military and HCA wells. Very small yields (4 to 40 L/min) will support most hand pump wells. Ground water exploration in this region would be costly and is not recommended.
7 Fresh water scarce or lacking	A relatively small coastal area in the northwestern corner of Guyana, consisting of unconsolidated clay and sand deposits. These deposits are Quaternary to Recent coastal plain marine sediments of the coastal unit. The shallow and unconfined to confined aquifer is in the Barima-Waini (0740N05945E) administrative division.	Large quantities of water are available from sand lenses.	Brackish to saline water is throughout most of the aquifer. Floating lenses of fresh water are locally present on top of the water table but are of limited quantities. Water becomes more saline toward the coast.	Depth to water is generally <30 m. Access is difficult due to lack of all-weather roads. Mud rotary drilling with steel bits is recommended to drill wells.	No recharge area has been defined for this aquifer, and the constant flushing of this region by the Atlantic Ocean keeps the TDS levels elevated. Overpumping of wells in this aquifer will draw in more saline water from the ocean. Large quantities (4,000 to 40,000 L/min) of water will support military or HCA wells.

[1]Quantitative Terms:
- Enormous = >400,000 L/min (100,000 gal/min)
- Very large = >40,000 to 400,000 L/min (10,000 to 100,000 gal/min)
- Large = >4,000 to 40,000 L/min (1,000 to 10,000 gal/min)
- Moderate = >400 to 4,000 L/min (100 to 1,000 gal/min)
- Small = >40 to 400 L/min (10 to 100 gal/min)
- Very small = >4 to 40 L/min (1 to 10 gal/min)
- Meager = $\leq$4 L/min (1 gal/min)

[2]Qualitative Terms:
- Fresh water = maximum TDS $\leq$1,000 mg/L; maximum chlorides $\leq$600 mg/L; and maximum sulfates $\leq$300 mg/L
- Brackish water = maximum TDS >1,000 mg/L but $\leq$15,000 mg/L
- Saline water = TDS >15,000 mg/L

Hardness Terms:
- Soft = 0 to 60 mg/L $CaCO_3$
- Moderately hard = 61 to 120 mg/L $CaCO_3$
- Hard = 121 to 180 mg/L $CaCO_3$
- Very hard = >180 mg/L $CaCO_3$

Table C-2. Ground Water Resources (continued)

[3]Geographic coordinates list latitude first for the Northern (N) or Southern (S) Hemisphere and longitude second for the Eastern (E) or Western (W) Hemisphere. For example:

Courantyne River . . . . (0323N05736W)

Geographic coordinates for the Courantyne River that are given as 0323N05736W equal 3°23'N 57°36' W and can be written as a latitude of 3 degrees and 23 minutes north and a longitude of 57 degrees and 36 minutes west. Geographic coordinates are sufficiently accurate for locating features on the country-scale map. Coordinates are approximate.

Note:

$CaCO_3$	= calcium carbonate
gal/d	= gallons per day
gal/h	= gallons per hour
gal/min	= gallons per minute
HCA	= humanitarian civic assistance
H_2S	= hydrogen sulfide
L/min	= liters per minute
mg/L	= milligrams per liter
ROWPU	= reverse osmosis water purification unit
TDS	= total dissolved solids

Conversion Chart:

To Convert	Multiply By	To Obtain
liters per minute	0.264	gallons per minute
liters per minute	15.852	gallons per hour
liters per minute	380.517	gallons per day